# ASTRONOMY

January 1980
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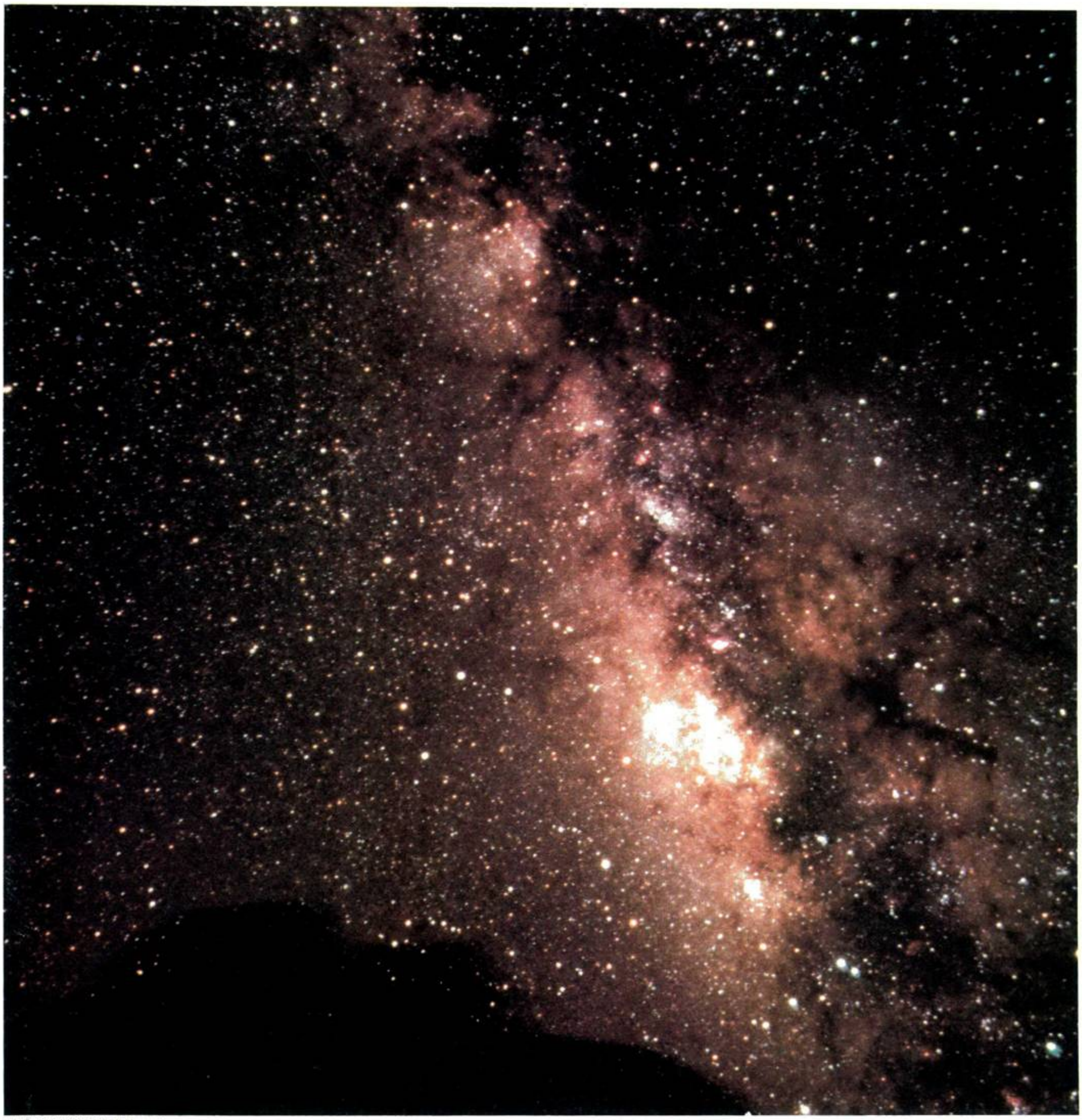
## Alien Eyes

## What Good Is An Erfle

## Observing Mars



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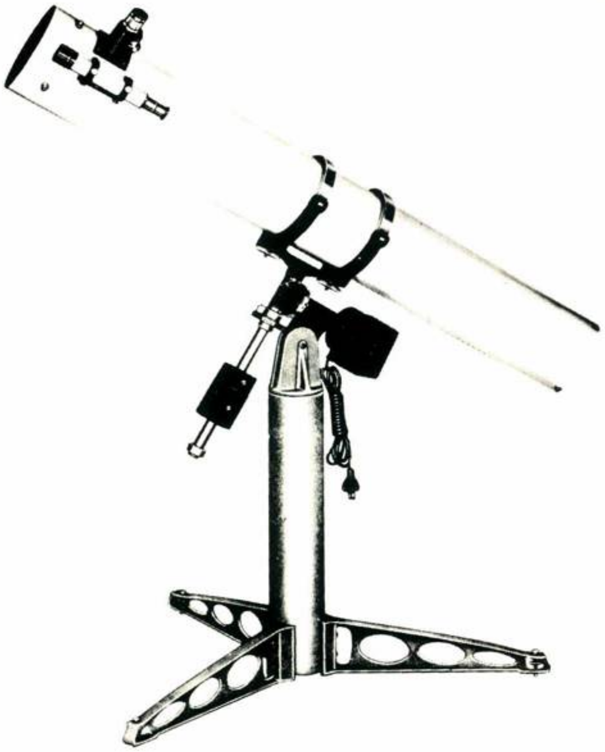

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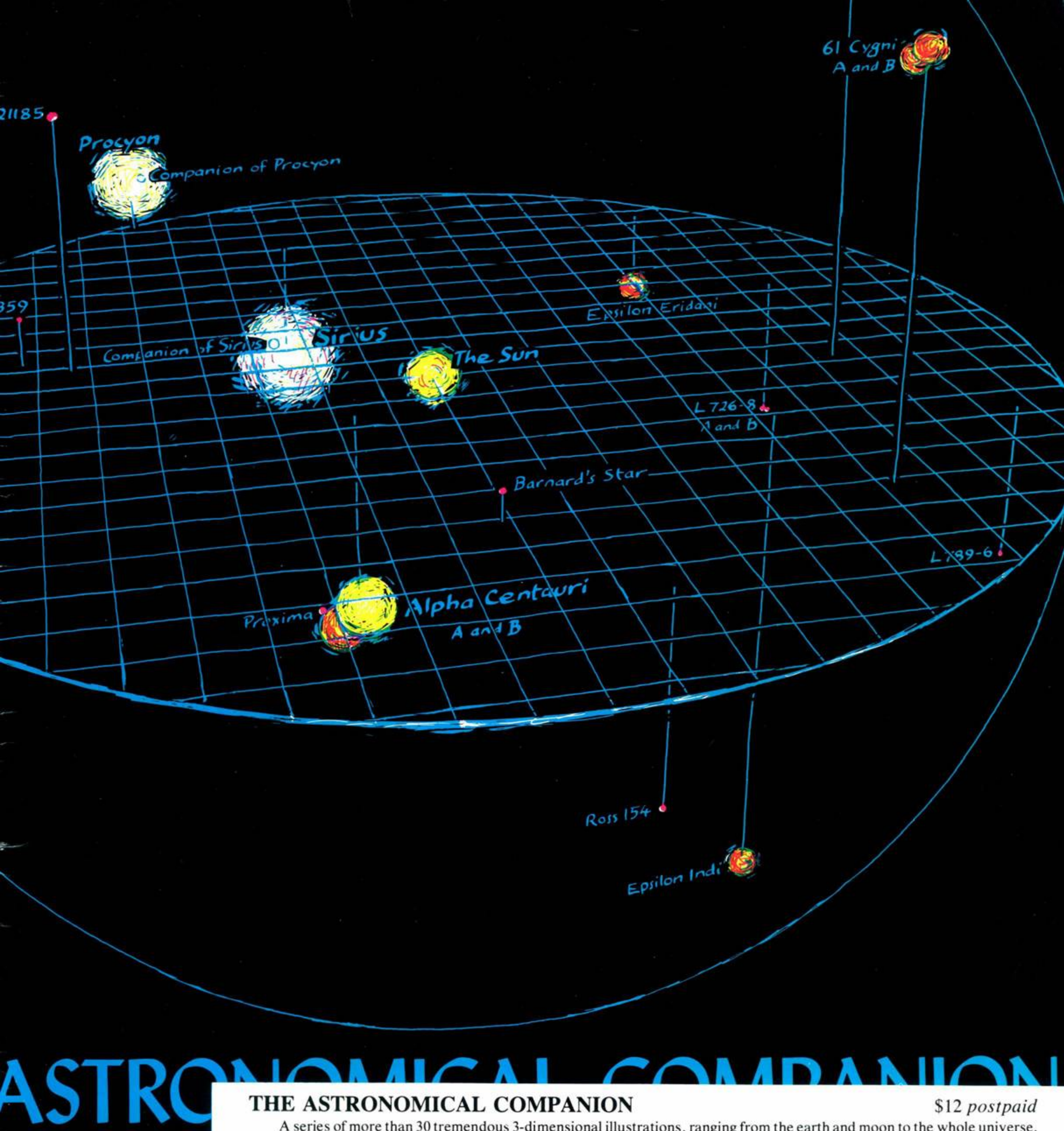
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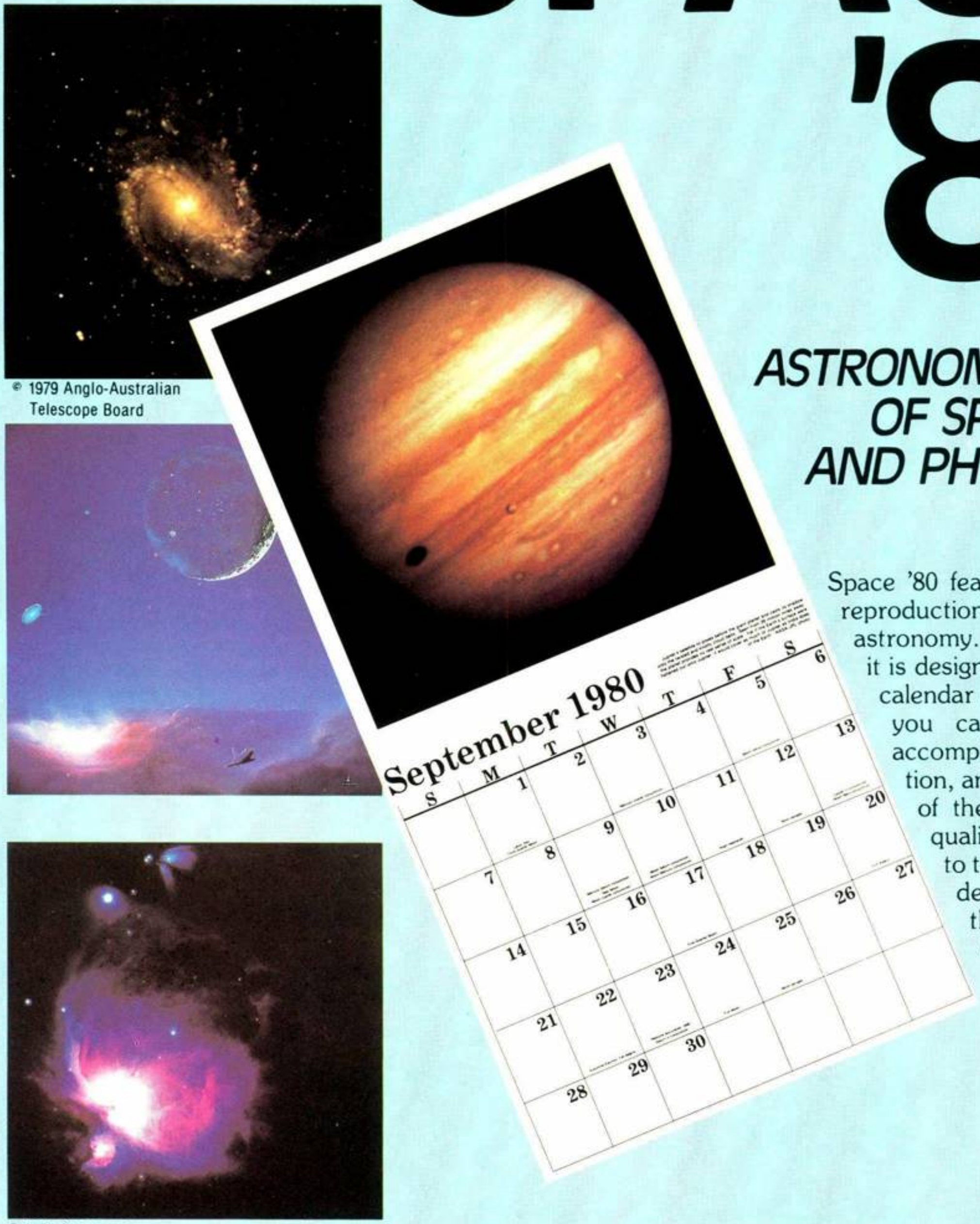

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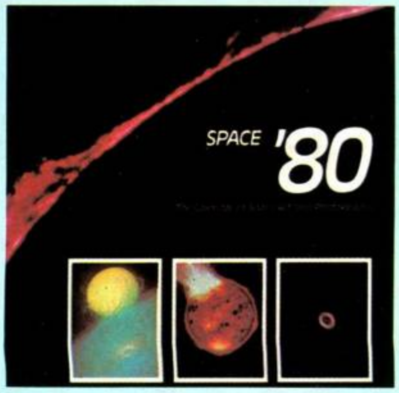

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Cover: The constellations of Sagittarius and Scorpius contain some of the richest fields of stars and nebulae in the entire sky. Here, concealed behind light-years of dust, lies the far-off core of the Galaxy. That region's undoubted splendors may never be seen directly, but even the obscuring material itself blazes forth with glorious sights. This month's Photography in Astronomy talks about two ways to capture some of these glories, and helps you choose between them. Photo by John Sanford.

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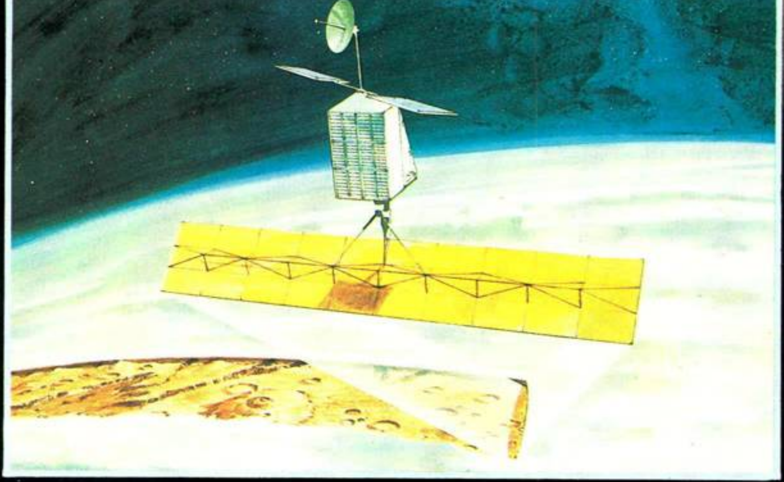
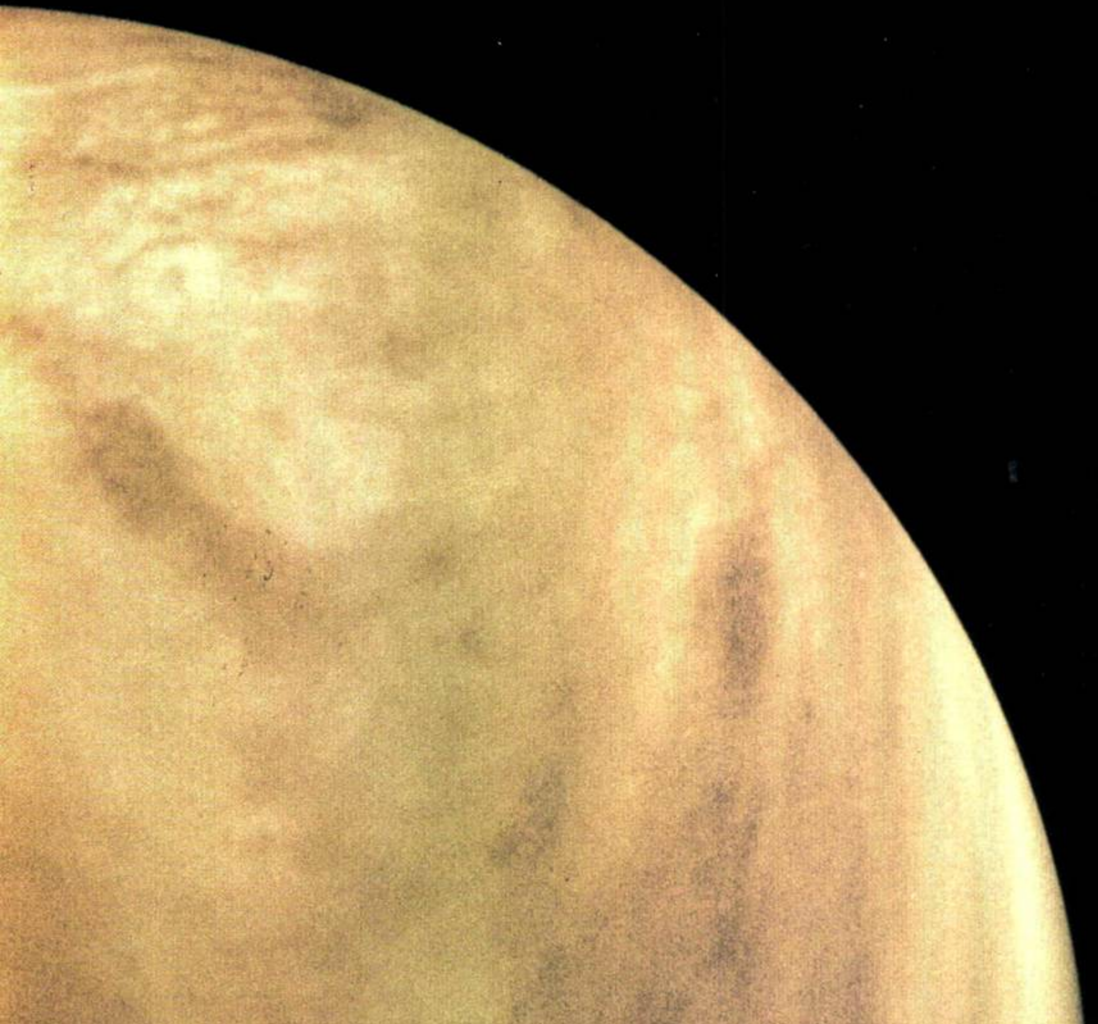
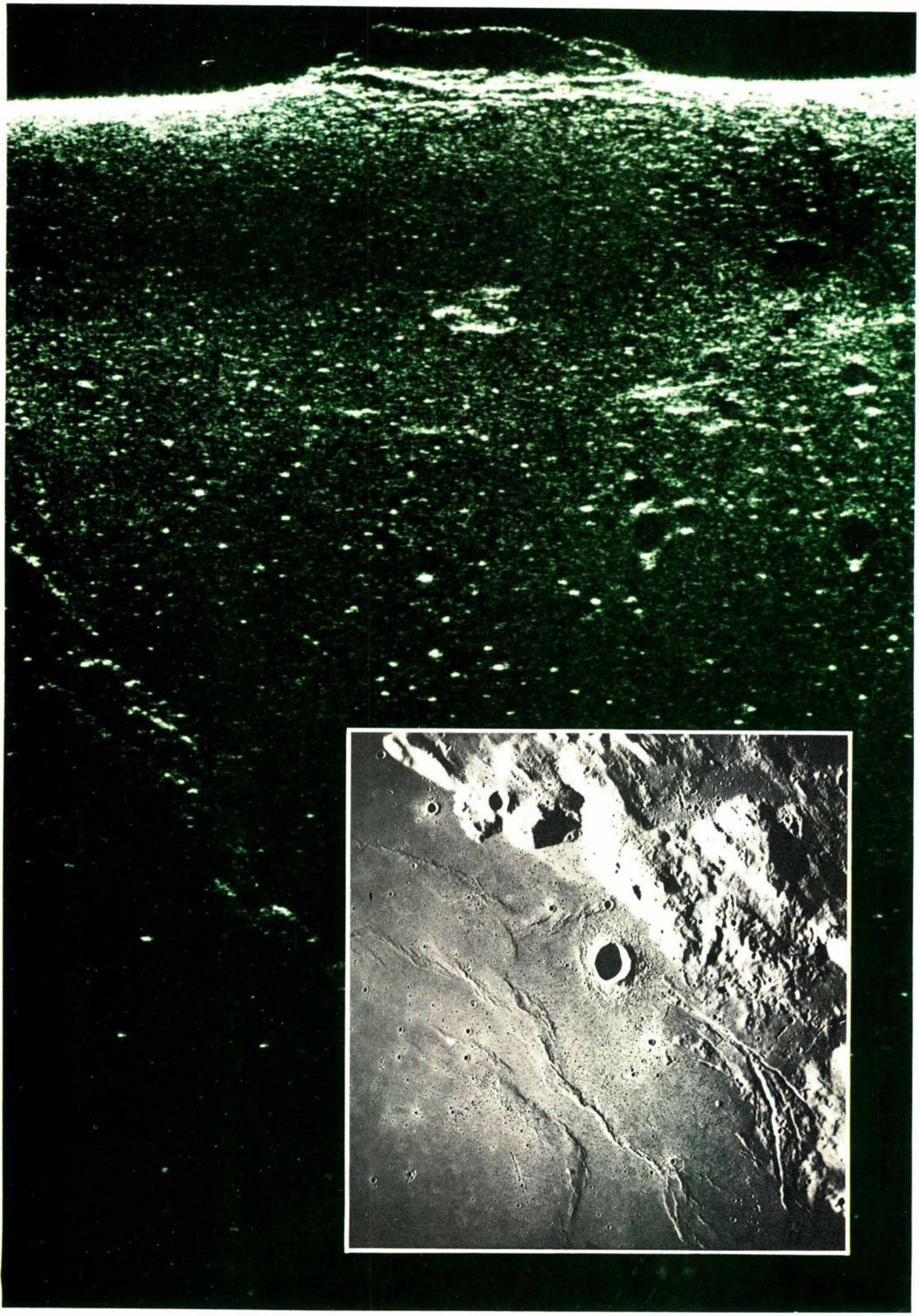
# ALIEN EYES

### by Michael Kobrick



Far below the racing cloud tops of Venus lies an unknown landscape. Rudimentary radar studies with Pioneer Venus have shown a rolling terrain dotted with craters and plateaus, but the details are scant and our understanding imperfect. Only radars such as that of the Venus Orbital Imaging Radar probe, shown here figuratively sweeping aside the clouds, will penetrate the murk and reveal the surface. The VOIR probe will map the entire surface of Venus to a resolution of a few hundred meters, just as Mars was first mapped by Mariner 9. NASA photo and painting.





Talk about frustration! For a moment put yourself in the shoes of a contemporary planetologist: you study rocks of all sizes, but are especially interested in how relatively large aggregations of them — planets — form, grow, and evolve. You've taken a good look at parts of planet Earth, walked around on it, hauled chunks of it home to the lab, and mapped the relationship of this rock to that one. But it's not enough.

You know that neither you nor your colleagues are going to get very far in piecing together the "Big Picture" if all you have is one sample planet. Comparisons may be odious, but no scientist can practice his trade without them. You need to start looking outward, and here NASA helps you. They even arrange to bring back bits of the Moon for study. Many of your questions are thereby settled, but far more arise to take their place.

Outward still the search goes, with cameras and other more arcane devices. Magnetometers tell you about planetary cores; seismographs in landers send back data on moonquakes and marsquakes. Financial constraints may prevent you from getting back actual samples, but remote-sensing techniques help you interpret the surface shapes of rocks. This long-distance research is frustrating in part — because you'd really like to get those rocks you see into a lab — but also satisfying since you're still learning a great deal.

Onward and outward: Mars, Mercury, even the Galilean moons fall one by one into the province of the geologist. But the big holdout remains that "twin-planet" sitting next door: Venus — and that's where the frustration bites deep.

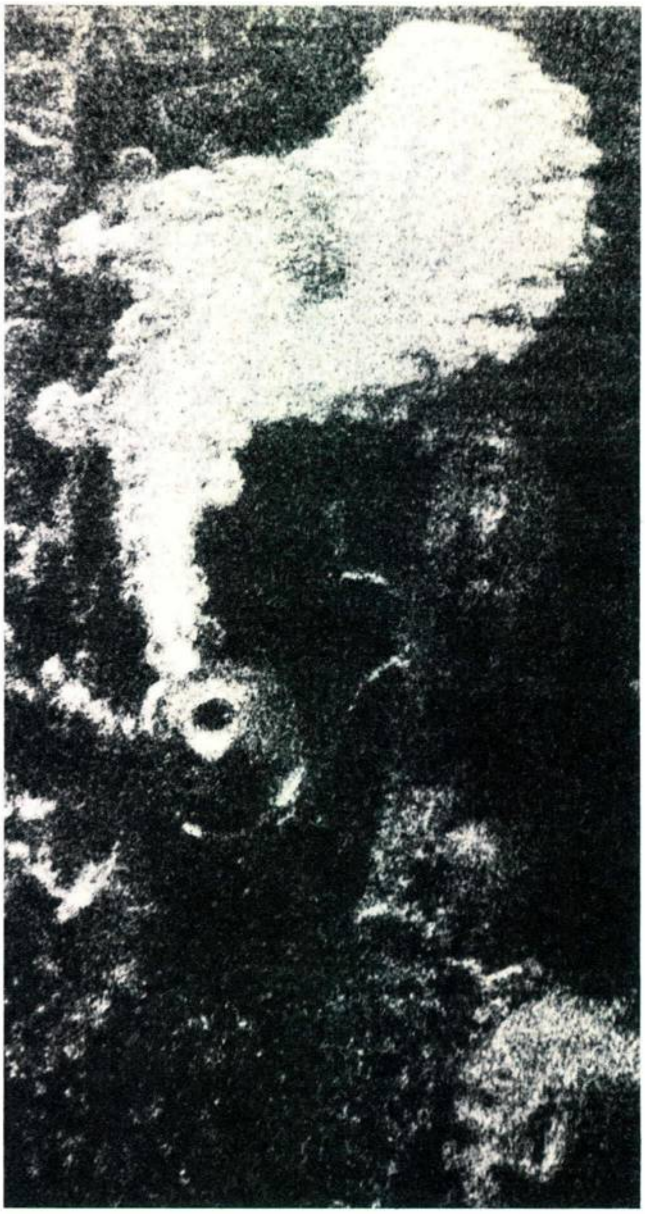
Venus' radius is 95% of Earth, its volume 88%, its mass 82%. A falling object on Earth drops 16 feet the first second; on Venus, 14 feet. Our planet's density is 5.5 times that of water; Venus', 5.2. On the other hand, its day is 224 of ours long (and it spins backward to boot), it has no seasons to speak of, and its atmosphere is crushingly heavy and hellishly hot.

In a word: Why?

We can't know. With the other terrestrial planets, scientists can fly equipment to take a look and make on-the-spot analyses. But Venus defies all easy approaches. Its sulphuric acid clouds, and high temperature, extreme pressure, and totally opaque blanket of atmosphere prevent any direct view and have destroyed every landing probe sent there within a short time after touchdown.

The Russian Venera 9 and 10 landers sent back only one picture each, showing a rocky, seemingly unweathered landscape directly in front of them. Other measurements suggest these rocks are granites. And that's about all anyone knows of the surface's close-up appearance.

At the other end of the scale, Pioneer Venus has returned data from its radar altimeter which have allowed a preliminary sorting of topographic highs and lows. Earth-based radar from Arecibo's 1000-foot dish has mapped a few areas in more detail. We are being teased by crude glimpses of details unknown — and so far unknowable.

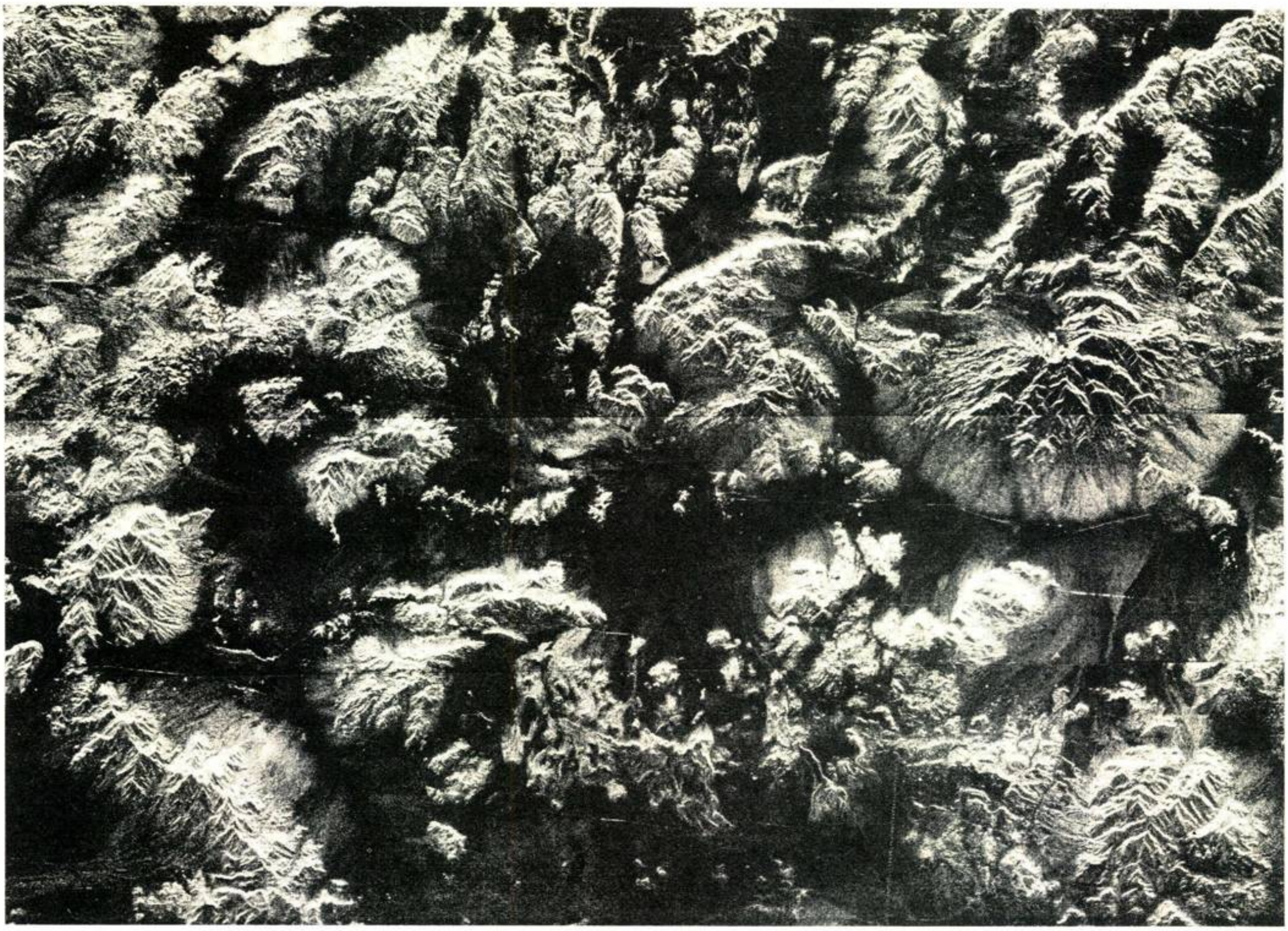


**The close similarity between radar images and ordinary photos makes their interpretation easier: here's a little volcanic cinder cone with a fresh lava flow. The extreme roughness of the lava causes it to backscatter the radar signal especially well; hence it appears bright. NASA/JPL image.**

**Apollo 17 carried an imaging radar into lunar orbit and used it in conjunction with conventional photography. The prominent crater is Sulpicius Gallus in Mare Serenitatis. In the radar image the crater appears as if on the horizon, while wrinkle ridges snake across the foreground. NASA images.**

Of course, there's far more to planetary science than surface geology: magnetic fields, seismic probing, and chemical analysis, to name just a few. But knowledge of what landforms exist and how they came to be is essential for an adequate understanding of any terrestrial planet or moon. So here's the problem: Unless a "fine-grain" method is found to scan its surface systematically, planetary scientists aren't likely to know very much about Venus' geology.

Is there any way to unpeel that global murk and peek beneath? Or are we forever stuck with choosing between fuzzy, low-resolution general views or the sharply-rendered, but tiny, landscapes of a myopic probe? The surprising answer is no, a middle method



In this Seasat image of the Mojave Desert, the relatively smooth desert floor appears dark, while mountains and surrounding rocky alluvial deposits appear bright. NASA image.

*does* exist. Though new and promising, it's been used only a short time here on Earth for resource mapping, and it forces the user into some mental gymnastics to get the most from it. But if Congress is willing, an updated version can soon be sent off to "see" — at last — the surface of our sister world.

Let's take a look at this amazing system and see what it has done and what we can expect it to do on Venus.

Spread over these pages are views of the Earth and Moon obtained from high altitude aircraft and orbiting spacecraft. Take a close look at them. They resemble standard aerial photographs, don't they? But they aren't, and these particular images were produced by a method as different from standard photography as a television set is from an optical telescope. This method seems to be unique in nature, and so constitutes an entirely new — you might even say "alien" — way of seeing.

The photos are produced by an imaging radar system known as *synthetic aperture radar* (SAR). Engineers have been working on the technique for at least 20 years, but only recently has it begun to attract the attention of scientists interested in the remote sensing and analysis of planetary surfaces.

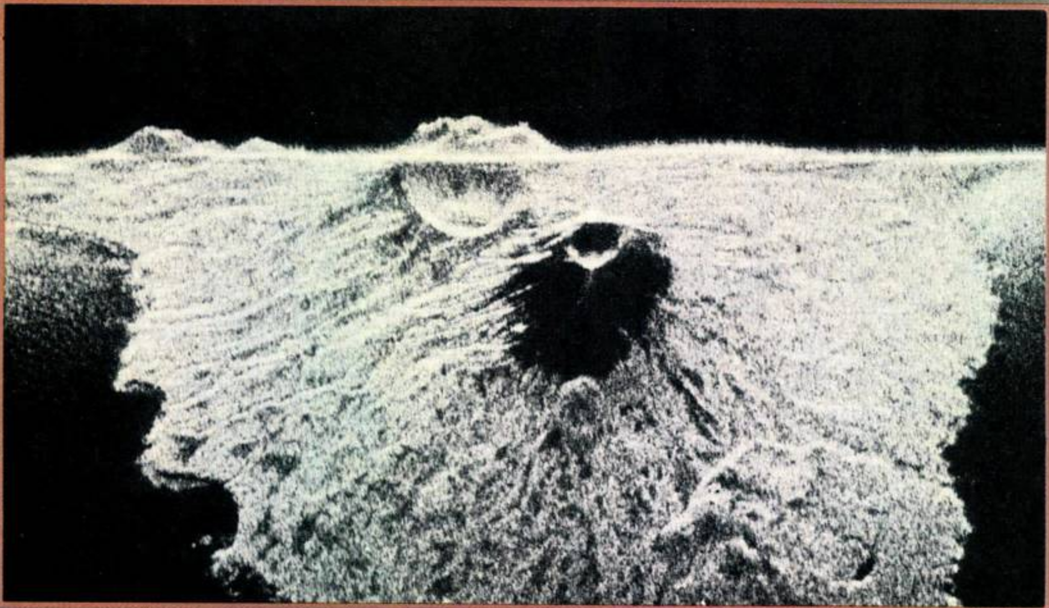
In June 1978, NASA launched the first civilian imaging radar into Earth orbit. Carried aloft aboard an experimental oceanographic satellite named Seasat, the radar was to have tested microwave radar imaging of the ocean surface under all weather conditions and was to send back information on storms, near-surface winds, currents, pollution, and several geophysical problems. As it happened, the spacecraft had a massive short-circuit a few months after launch and "died," but not before returning a plethora of extremely high-quality images.

Although not designed to image Earth's solid surface, Seasat's SAR gave views of mountain chains, volcanos, canyons, and other geologic features so spectacular that earth scientists became quite excited about radar mapping. Indeed, NASA has earmarked an imaging radar for the very first Shuttle mission to carry scientific instruments. A few years after that, we should be marveling at the first orbital pictures of the surface of Venus.

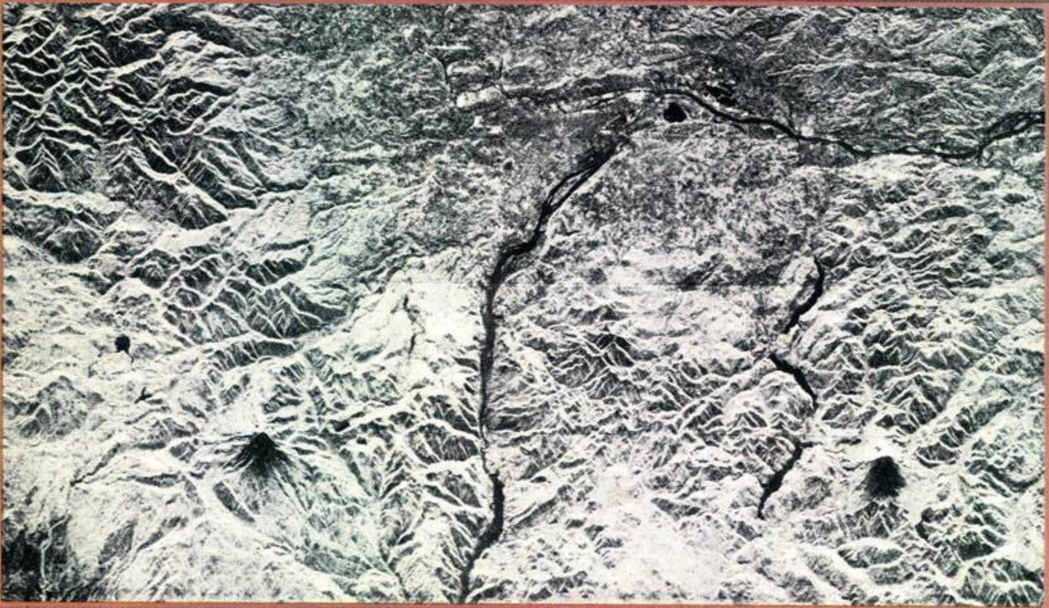
All right, just how do these radars work and what do their images tell us?

First of all, imaging radar differs from a conventional camera in that it uses another part of the electromagnetic spectrum. The wavelength of ordinary visible light ranges from about 400 to 700 nanometers (billionths of a meter). The reflectivities and colors we sense with our eyes (or a camera) arise from the interactions of light waves with electrons in the outer shell of atoms and molecules which make up the object we view.

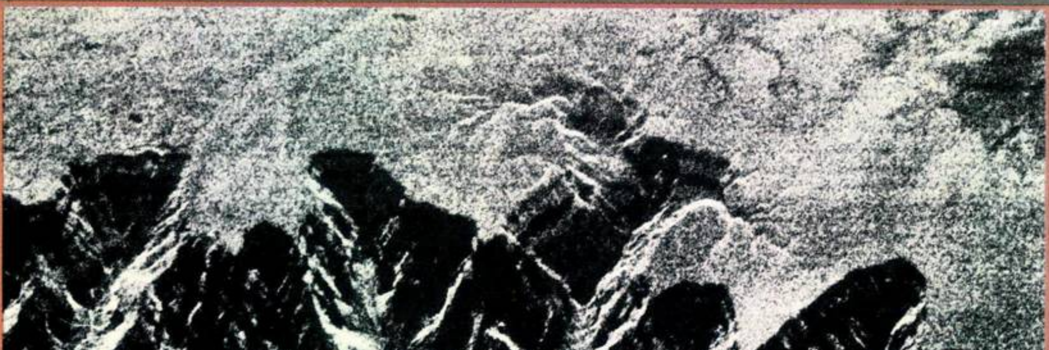
Radars, on the other hand, use much longer wavelengths ranging from about a centimeter up to many meters. In a radar image the brightness is caused by the radio waves scattering not from



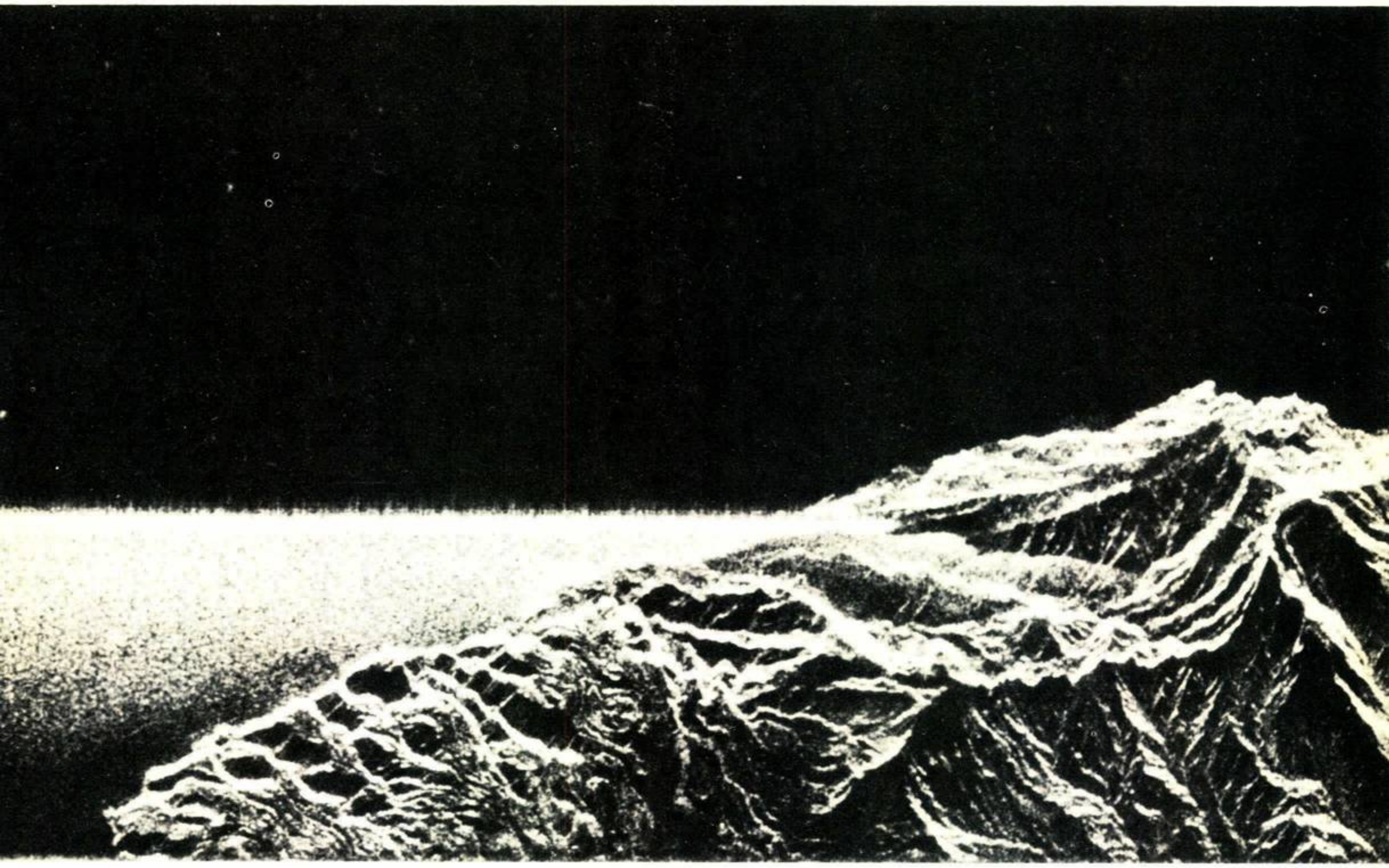
**Mt. Edgecumbe in Alaska is a volcanic peak on a peninsula extending into the Pacific Ocean. Its summit caldera is about a half-kilometer in diameter. The dark area near the peak is due to a combination of radar shadow and a change in surface texture (rocks or vegetation). NASA/JPL image.**



**During its brief operational lifetime, Seasat demonstrated what an imaging radar could do. Here we see part of the Columbia River basin. The view is toward the west, with Oregon to the left, Washington to the right. The two sharp peaks are Mts. Hood (left) and St. Helen. NASA image.**



**The Grand Canyon's south rim stands out boldly here. Pioneer Venus data have indicated that at least one large rift valley exists on Venus. The images' clear detailing of rock strata will help analysts decipher the geological history of Venus' surface. NASA/JPL image.**



individual atoms, but from surface features having a roughness of about wavelength-size or larger. One of the major problems facing scientists who try to interpret radar images is understanding the complicated details of the scattering processes.

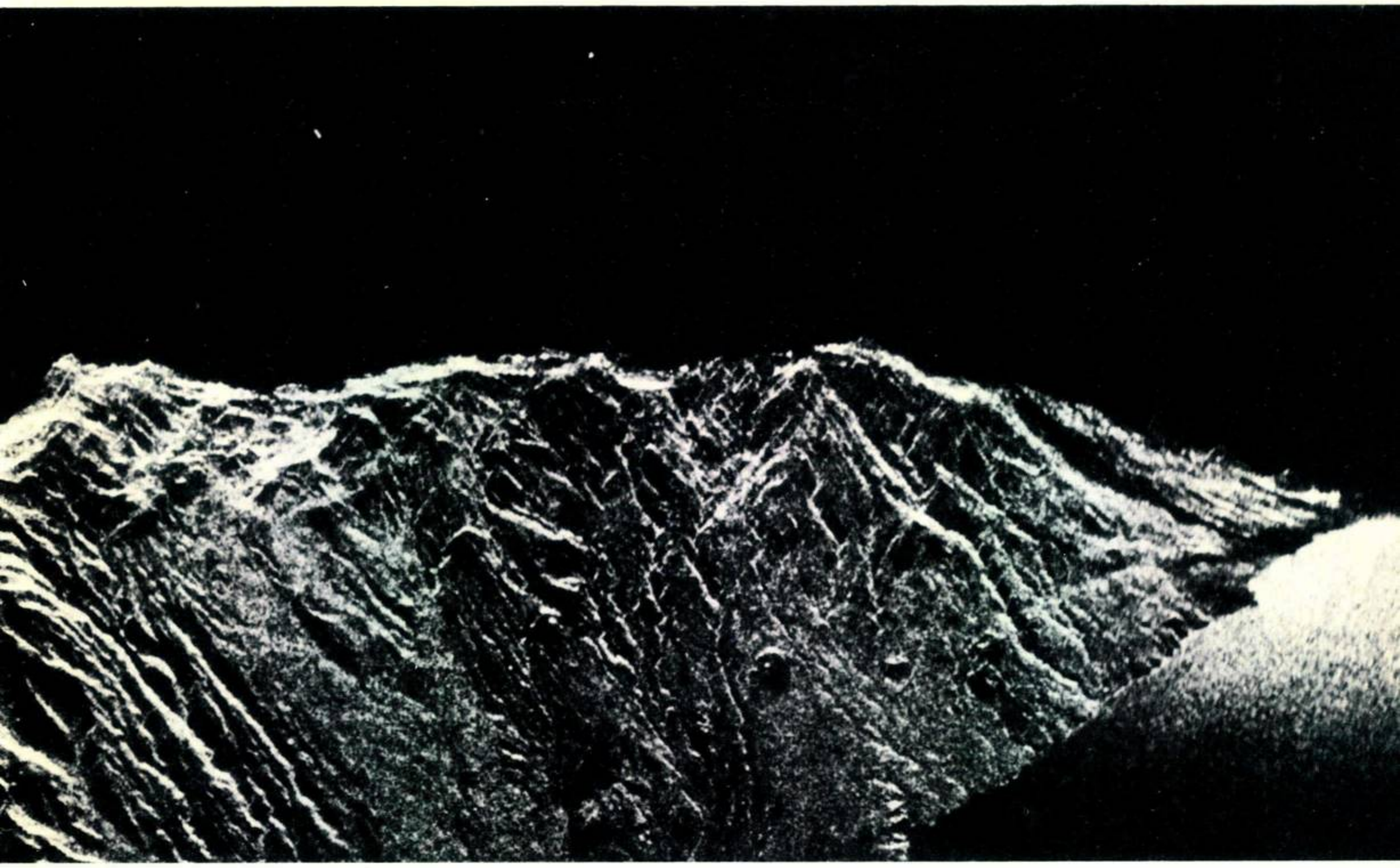
But merely operating in a different part of the spectrum isn't all that unusual. Images of astronomical objects produced by radio waves, infrared, ultraviolet, and even X-rays, are now commonplace. An imaging radar picture differs from all of these in that the instrument producing them is "active." A SAR doesn't just sit there and receive radiation emitted by an object. It beams energy toward the target and records the portion reflected directly back. (Scientists call this *backscatter.*) The principle is like attaching a flashgun to your camera to take pictures in the dark. Not only does the radar produce its own illumination, but also its radio waves penetrate visually opaque clouds to make images at any time, day or night, in any weather.

This eliminates one of the annoying drawbacks of conventional photography. Scientists interpreting the Mariner or Viking pictures of Mars, for example, have to contend with different lighting conditions and viewing geometries in almost every image. Some earth satellites such as Landsat avoid this problem by having special "synchronous" orbits. Landsat always passes over any given spot at about 9 a.m. local time so the solar illumination stays more or less constant. Achieving and maintaining such an orbit around other planets is possible but costs a lot in terms of fuel and payload. By using radar, the problem is surmounted; the illumination angle always remains constant.

This flashgun technique, however, does create one problem. When radiation is emitted by a source (antenna, flashlamp, or whatever), it decreases in intensity as the square of the distance. Since the radar waves must make a two-way trip, the echo weakens as the fourth power of the distance. This means that when the radar looks just a little farther away, it receives back a lot less reflected energy. You notice the same effect when taking flash pictures: people or objects in the foreground appear quite bright or even overexposed, while those in the background may barely be visible. Radar engineers always face this "energy crisis" and must carefully calculate the echo strength they expect from a given target in designing their transmitters and receivers.

**Is there any way to unpeel Venus' global murk and peek beneath? Or are we stuck with choosing between fuzzy, low-resolution general views or sharply-rendered, but tiny, landscapes of a myopic probe?**

But even this active property doesn't make an imaging radar unique. After all, bats, dolphins, and camera owners have long been using the same principle. What makes the radar so unusual is what's



Santa Antao Island lies off the coast of northwest Africa. Here the aircraft carrying the radar flew directly over the island, but the curious imaging geometry of the system makes the island look like it's on the horizon. NASA/JPL image.

done with the radiation it receives. Eyes, cameras, telescopes, and most other imaging systems work on a technique in which both the intensity of a given reflected signal and the angle at which it enters the system (through a lens, mirror, or whatever) determine the location and brightness of a given point in the image. This is ordinary, everyday imaging.

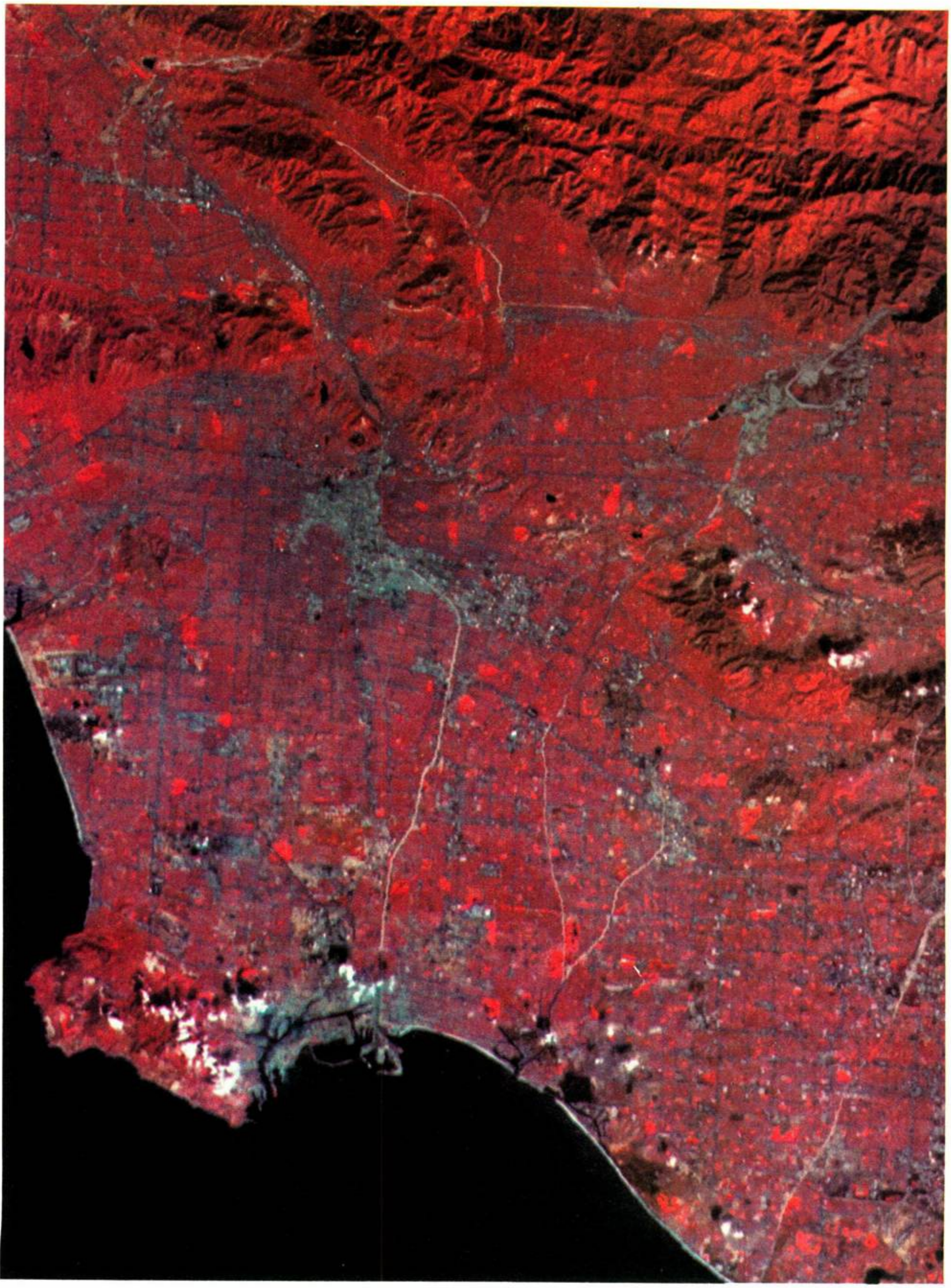
Radar imagers, on the other hand, cannot directly detect the angle at which the energy enters the antenna, at least not to the necessary accuracy. However, to form a recognizable two-dimensional image, they must still detect at least two properties of the reflected signal.

The first property the radar can observe is the *time delay*, or the interval between when the antenna sends the signal and when it is received back. This is generally a very short time indeed. In the case of Seasat, which had an 800 kilometer high orbit, a given bundle of energy traveling at the speed of light went from the satellite to the ground and back again in less than three milliseconds (thousandths of a second).

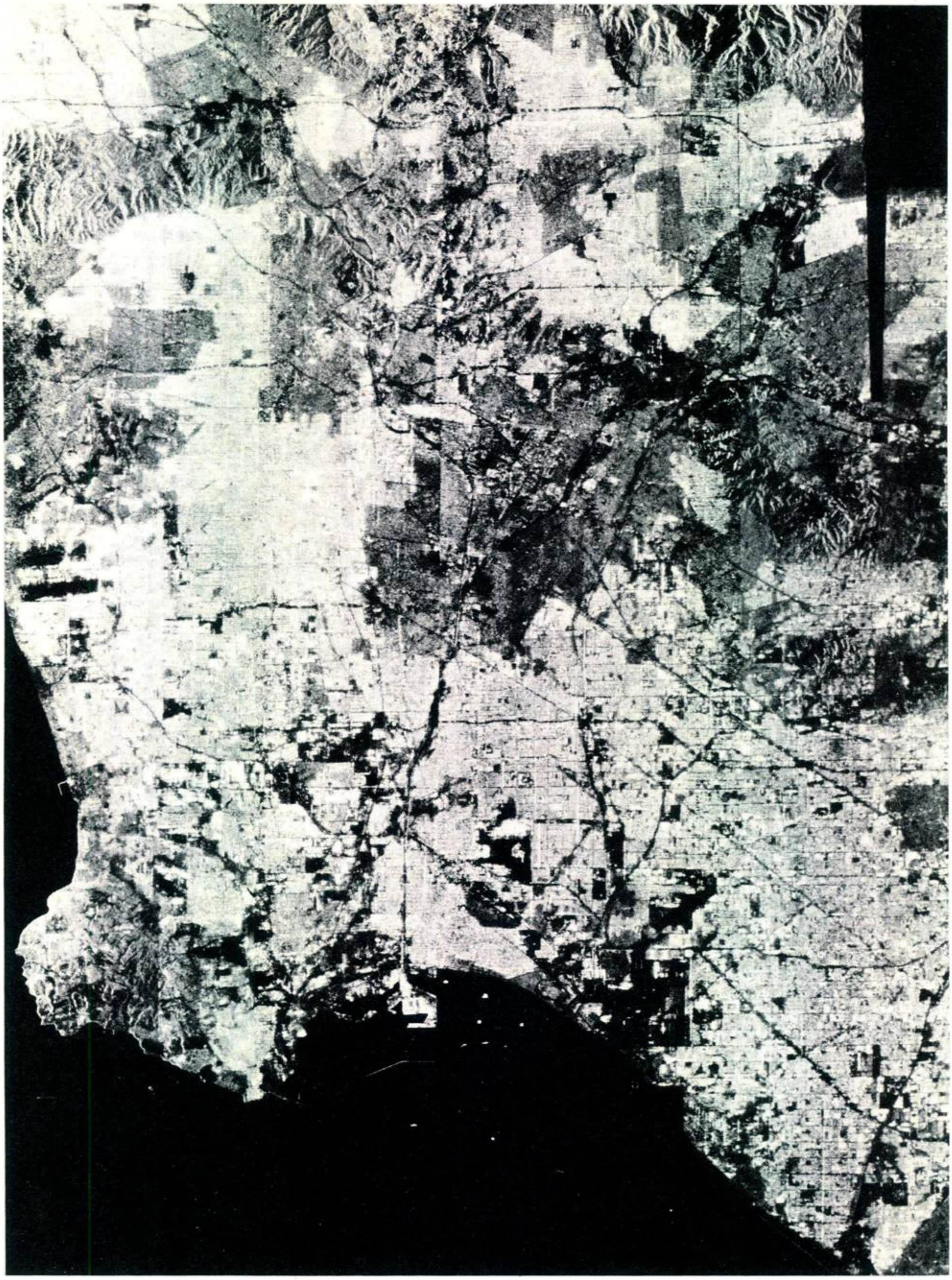
The radar aboard was capable of measuring time differences as short as one ten-millionth of a second, which translates into a vertical ground resolution of better than seven meters. (Roughly, resolution is the size of the smallest recognizable object.) The images on these pages have had some resolution elements averaged together to reduce a "twinkling" effect produced by radar targets as they pass through the beam, so the effective resolution is actually about twenty-five meters. For comparison, the optical and infrared cameras of the latest Landsat have resolutions of around forty meters.

The second property of the echo that imaging radars use is the signal's apparent change in wavelength due to relative motion between the radar and the target, the well-known *Doppler effect*. For a spaceborne radar the majority of this motion comes from the orbital velocity of the satellite. Generally, the antenna looks off to one side, perpendicular to the direction of flight. As an individual target enters the antenna beam (which is a few degrees wide), its echo displays a small positive Doppler shift which then decreases to zero and becomes negative by the time it leaves the back edge of the beam. The radar's computer records the *Doppler history* for each individual target, and creates a "synthetic" aperture equal to the length of time a target is in the beam multiplied by the radar's velocity.

This method is similar to the aperture synthesis technique of radio astronomy, where an antenna can be moved along the ground to fill in the space between two other antennas creating an effective antenna equal in size to the distance between the two fixed antennas (see "Using Earth as a Radio Telescope," ASTRONOMY, October 1979). The effective antenna created by Seasat was 14.8



This Landsat photo shows the city of Los Angeles. The wavelengths used include false-color infrared, so the red areas are covered in vegetation. NASA image.



The radar image is noticeably crisper, and the peculiar properties of the radar record features unseen by Landsat — such as the oil well towers in the ocean off Long Beach (bottom center). NASA/JPL image.

**Heavily mountainous regions like the western coastal range in British Columbia provide interpreters with special problems since details from one set of hills can be superimposed on another. NASA image.**

kilometers long. This gave a resolution in the direction of flight equal to that attained in the vertical direction by the time resolution.

The ability to measure both time differences and Doppler shifts lies wholly in the radar's hardware, so it isn't affected by the distance to the terrain. No matter how high the orbit, the resolution of a given radar is the same. If a football field-sized crater is just recognizable from a 100 km orbit, it will be equally as recognizable from 1000 km (assuming the fourth power law hasn't reduced the signal below detectability). Does that seem contrary to common sense? Remember that your common sense is just the result of a lifetime's experience with angle measuring devices (your eyes) which do, of course, degrade with distance; radar is different.

So a SAR image actually displays radar brightness versus time delay and Doppler shift. This may sound intimidating, but fortunately the images bear a strong resemblance to regular aerial photographs and can be analyzed the same way if you keep three geometric tricks in mind.

First, you need to know that the apparent angle of view on the terrain is perpendicular to that from which the radar actually made the image. For example, if the landforms look like they are on the horizon, then the radar was directly above them (the image of Santa Antao Island shows this well). If the view is from "above," then the object was actually on the horizon. Of course, these are the extremes; intermediate "look-angles" are also used, which give the most recognizable images of all.

Most image interpreters were brought up on photographs taken nearly straight down, and so they tend to prefer similar radar images. This means using a very large look-angle, almost horizontal. This drives the engineers nuts because large look-angle radars are more difficult to build (the radar "energy crisis" again).

The second trick is to remember that the illumination source is always at the radar. Thus an image at small (vertical) look-angle will resemble a photograph of the horizon taken at noon, while one at large look-angle appears similar to a photograph taken almost straight down with a low Sun. Straight-down images with very low-angle illumination have an advantage for photogeologists, since the extensive shadows enhance more subtle topographic features.

The third trick is really surprising, and slightly complicated to explain. Imagine, for a start, that you are photographing a nice symmetric mountain from directly above it. Your picture will show both sides of the mountain the same size with the mountain top directly in the center. If you move off to one side, but keep your camera pointed at the mountain top, successive pictures will show the far slope becoming smaller and smaller while the nearer one will seem to expand. This effect is called *foreshortening*.

The surprise comes as you pass the point at which you are looking directly down the opposite slope of the mountain. In your optical photograph, the opposite slope will disappear (since you can't see through solid earth) and the mountain top will begin to appear in silhouette. But in the equivalent radar image, remember the detector is 90° away from your apparent position and is still illuminating that opposite slope. As a result, you will continue to see the other side of the mountain, even when it is beyond the "horizon." The other slope will appear superimposed on terrain farther away, a very confusing effect radar scientists call *layover*.

Fortunately, this usually only happens with very complicated or mountainous terrain, or when the radar looks down almost exactly vertically. Since it was designed primarily to image the flat ocean surface, Seasat's radar had a vertical look-angle, and so layover becomes noticeable in the mountain images.

With these principles understood, you only have to remember a few basic facts about radar to start understanding the light and dark areas. Metal reflects radar waves quite well and thus water towers, metal roofs, and high voltage transmission lines all appear as bright points in radar images. Slopes and roughness are also important in determining image brightness.

If the imager looks straight down at a fairly flat surface, a lot of energy comes back to the receiver. This is specular, or mirrorlike, reflection. As a surface begins to slope away from the radar, it backscatters less and less and so appears progressively darker. Also, the rougher it is (fields of boulders or lava blocks), generally the brighter it appears. On top of this are complicating effects due to differences in the density, electrical properties of the rocks, and the amount of liquid water present. Lastly, what's under the surface may be important, too, because unlike visible light, longer radar waves tend to penetrate surfaces.

**Effortlessly piercing the opaque clouds shrouding Venus, radio waves can lay bare for our scrutiny a landscape that's been hidden for eons.**

Obviously, interpreting radar images is not a trivial task. You need to remember the differences in viewing geometry and at the same time try to sort out all the different effects that contribute to the brightness in a radar image. In fact it helps if you try to forget all you ever knew about photography and vision in general, and actually try to think in terms of time delay and Doppler shift, like a bat or perhaps an alien who evolved on a perpetually dark planet.

Sound a little like "Zen and the Art of Image Interpretation"? It is. But in a few years we'll be seeing radar images of Venus and scientists will be deciphering the physical structure and evolution of an entire planet from them. Their success will depend strongly on how well they've been able to train themselves to see through alien eyes.

---

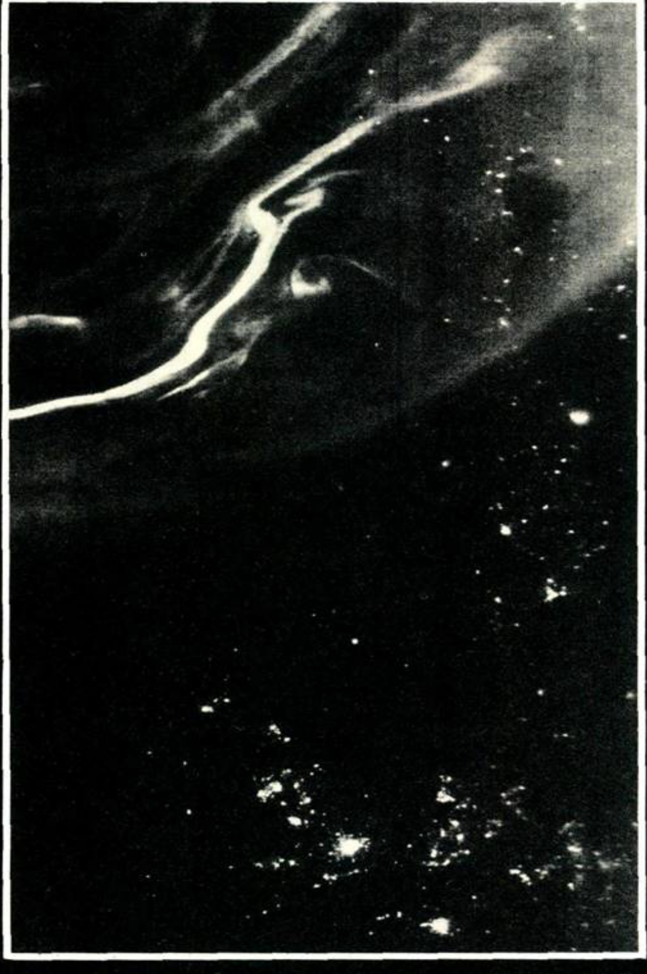
*Michael Kobrick is a radar scientist at Caltech's Jet Propulsion Laboratory. He studied planetary science at UCLA, and has been working for the last few years on applications of imaging radars to planetology.*

# NIGHT LIGHTS

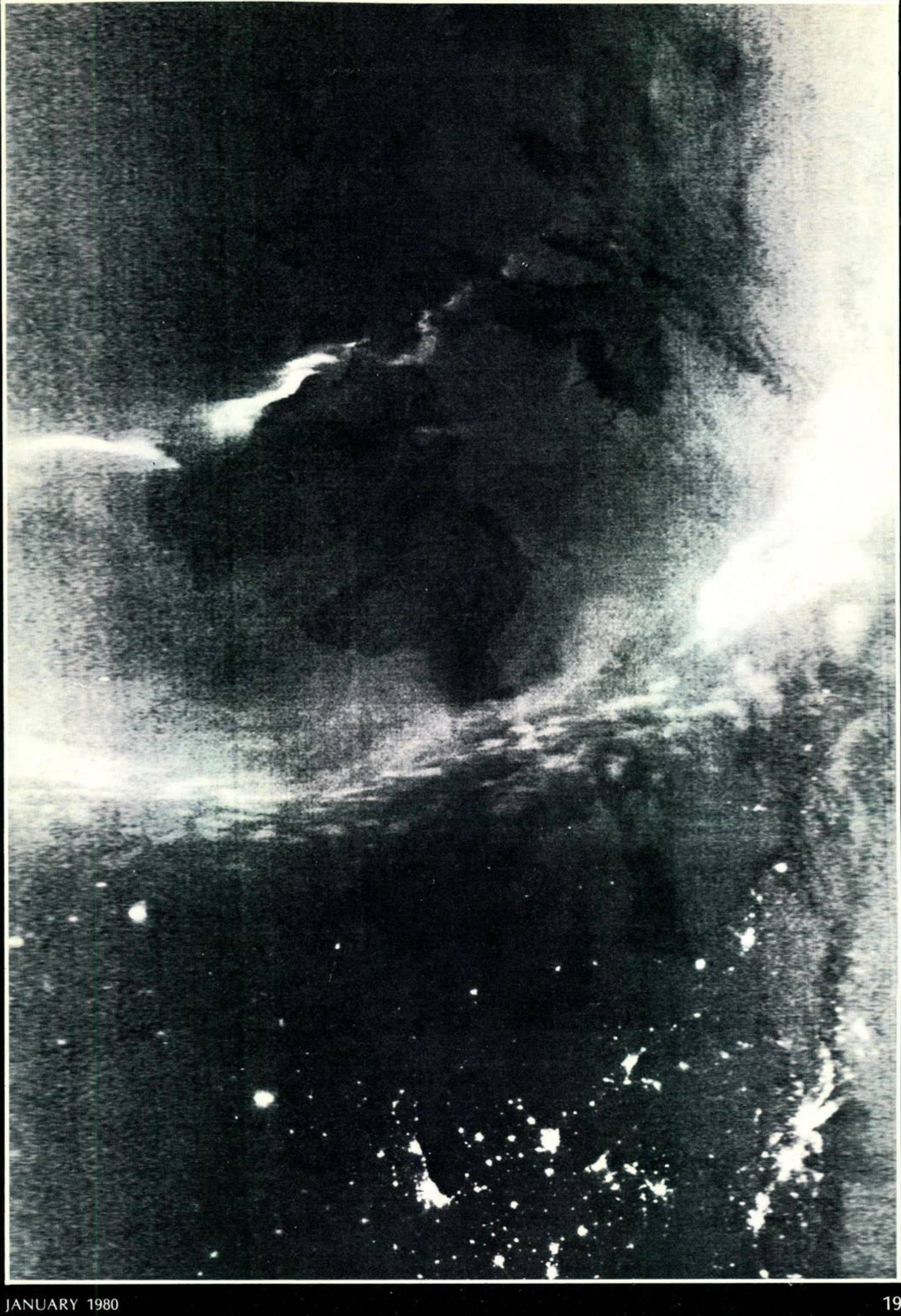
**by**
**Henry W. Brandli**

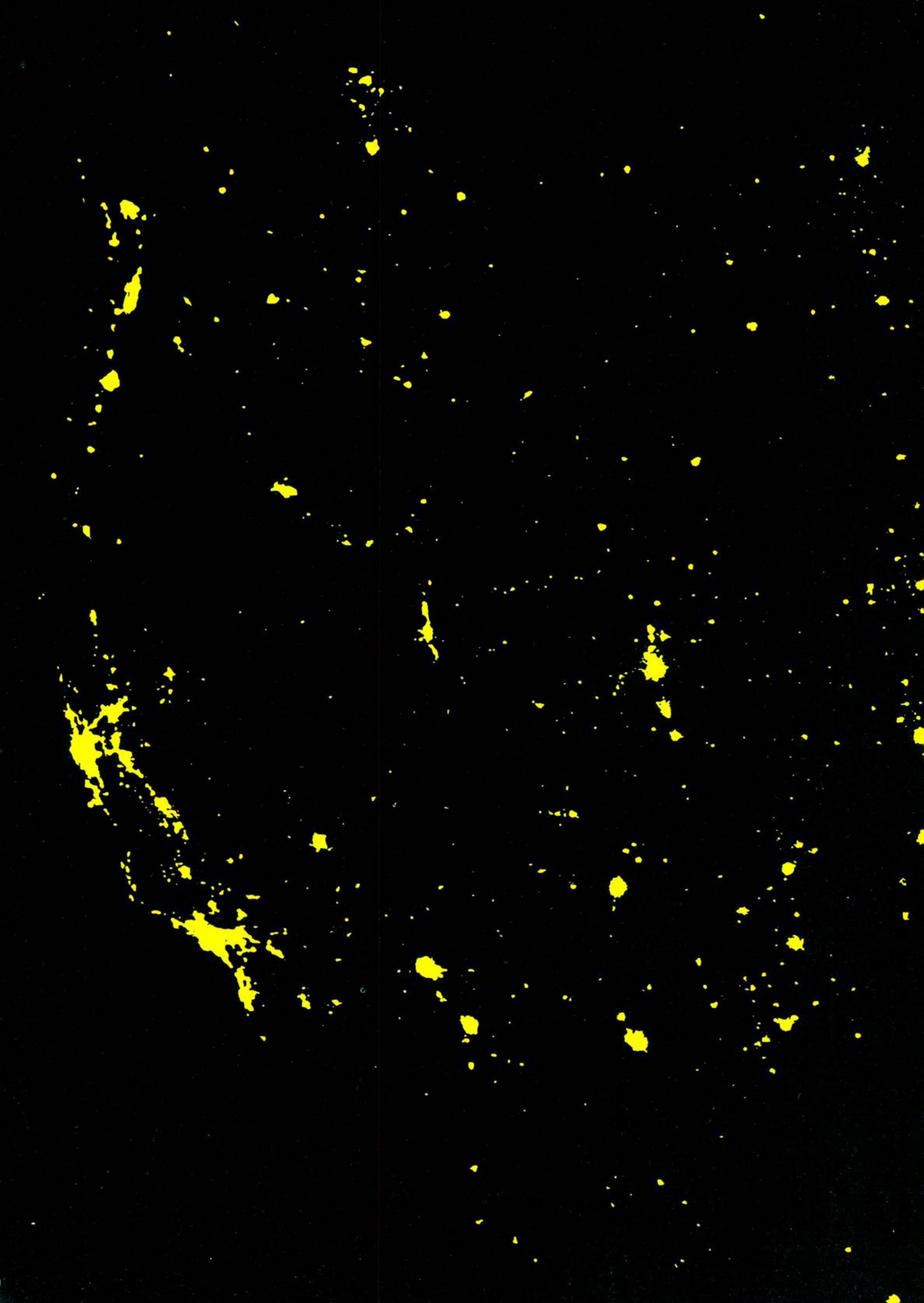
Every night weather satellites with ultrasensitive visual sensors photograph the dark side of the entire world. These satellites, part of a meteorological system owned and operated by the Department of Defense, belong to the Defense Meteorological Satellite Program (DMSP) — they take more than just "cloud pictures."

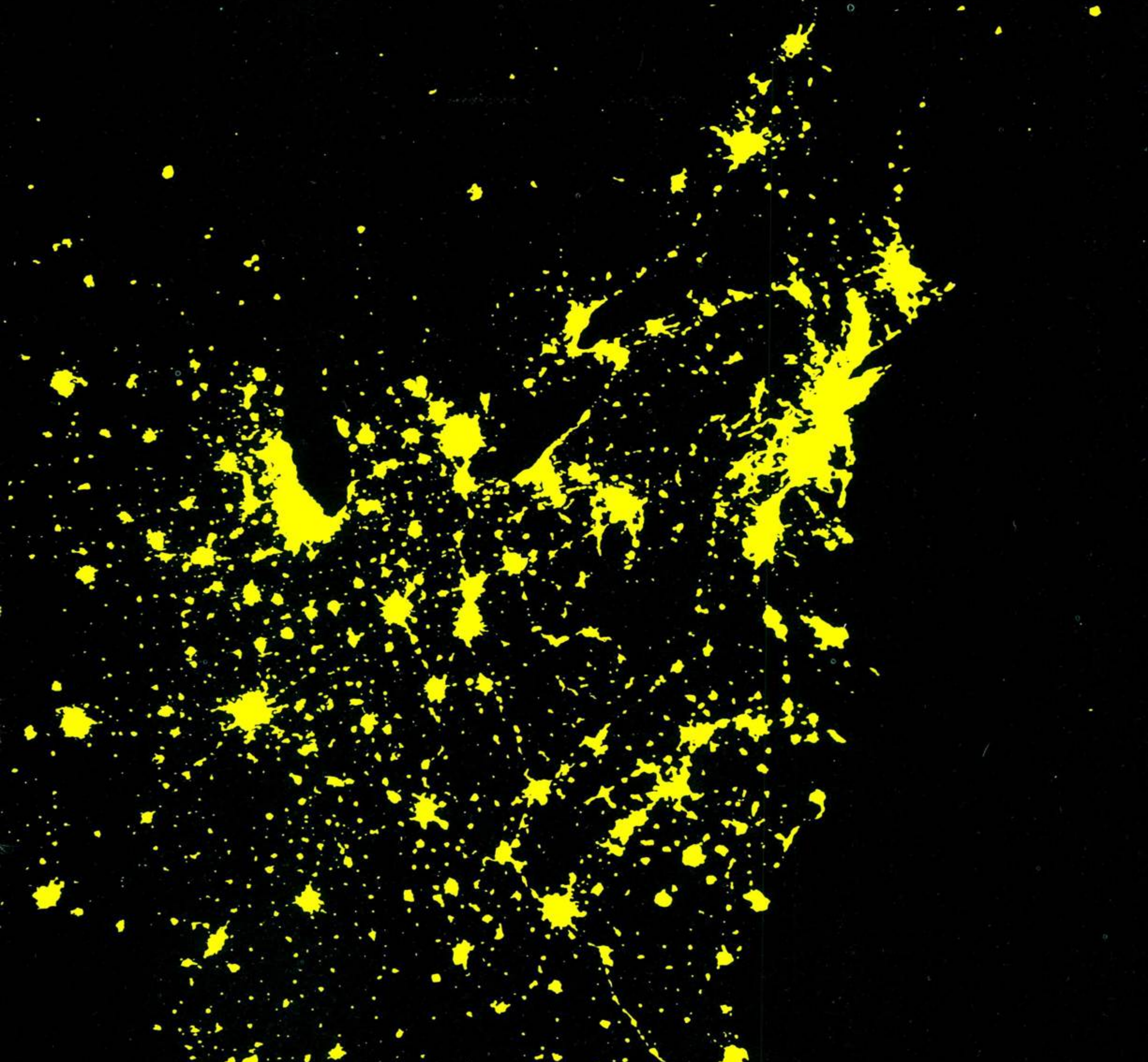
From 450 miles high, the satellites' sun-synchronous polar orbits allow them to photograph every spot on Earth at the same local time each day and night. Many natural phenomena stand out: the aurora borealis (northern lights) and aurora australis (southern lights) sometimes wreathe the poles with ghostly luminance. Volcanos, at least during active eruption, are spotted by the satellites; forest fires,



Right: The aurora borealis shines above the North Atlantic Ocean and Europe. The Scandinavian Peninsula is seen at the right; near the bottom center are the lights of London and Paris. Opposite page: Hudson's Bay stands out dark against the snow-covered ground lit by auroral light. Near the bottom of the frame are American cities from the Midwest to the East Coast.



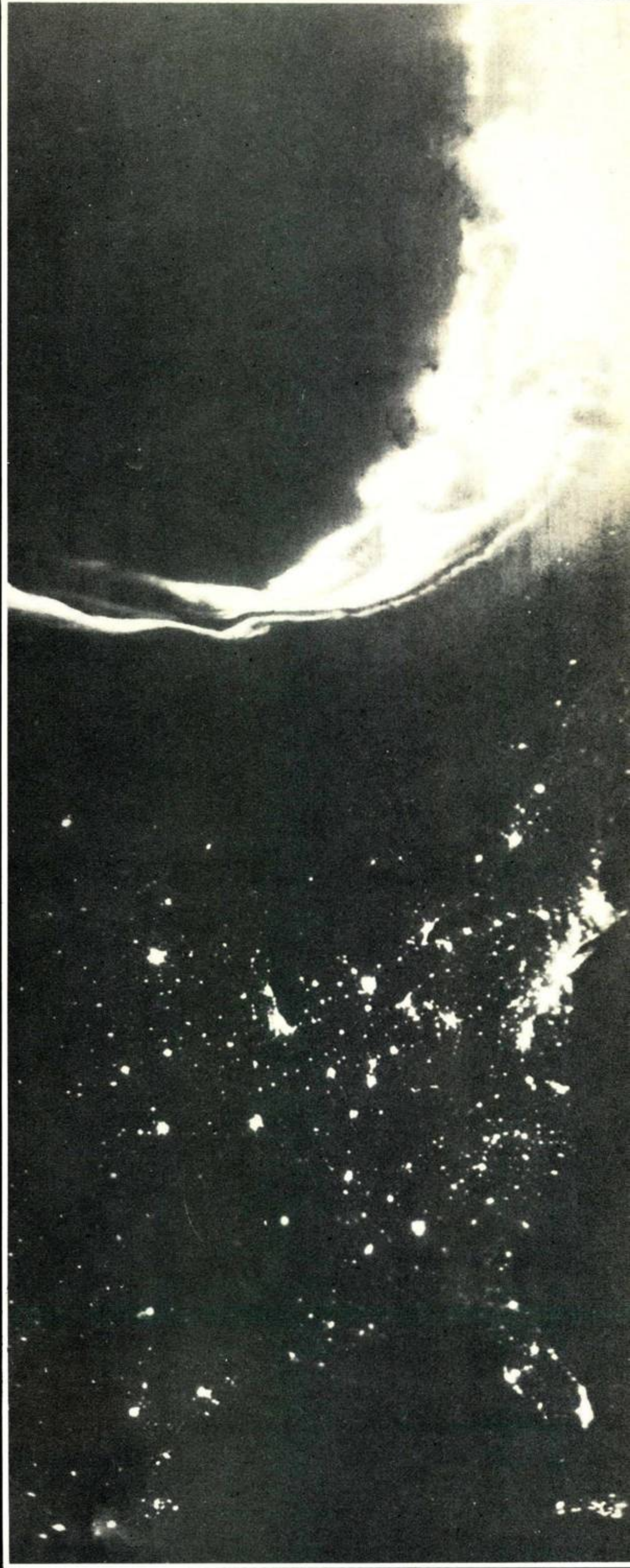




# The Night Face of North America

Shining against the darkness of night,
millions of city lights tell a story of prodigious energy consumption,
and map the location of human activity.
Can you find your home town?
If it has over 5,000 population, you probably can.

Right: From the Arctic Circle south to Mexico and Cuba, the DMSP monitors light and heat-producing activities at night. The images, such as this one showing a brilliant band of aurora, have been a boon to scientists. Opposite page: The weather across the great stretch of the North Atlantic Ocean is shown in a single DMSP frame. Lights of New York shine in the lower left, an aurora sweeps a great arc, and moonlit clouds cover the ocean surface. Inset: Night monitoring of weather can save lives: in this moonlit scene, hurricane Anita sweeps across the Gulf of Mexico.



lightning, and even meteor trails stand out as the DMSP satellites pass over twice each night — once just after dark and once around local midnight.

All these natural phenomena would have been visible at any time in the history of our planet, but the night view of Earth shows us how far we've come. Although man has thus far failed to make Earth's technological culture obvious from space during the daytime, the dark side of Earth is aglow with city lighting. Cities, highway routes, airports, military bases, fishing boats, and oil well burnoffs — just to name a few — show up "as bright as day" at night.

The usefulness of this nighttime reconnaissance is obvious: we can monitor our prodigious consumption of energy in outdoor night lighting and the growth of cities and population centers, watch the progress of lightning storms, and pinpoint the location of interesting features found in the simultaneous infrared ("heat") measurements made by DMSP.

The aurora mapping is vital to electronic communication operations and planning, and atmosphere/earth electrical studies. The aurora also sometimes provides enough light, especially helpful when the Moon is not up, to pick out such sea features as ice fields and icebergs.

And, of course, the DMSP is also used to study the weather with up-to-date forecasts, long range forecasts, and climatological studies. ◆

# ASTRONOMY FORUM

## Solar Sailing

In only a few decades we may see the solar system crisscrossed by huge sailing vessels, tacking and running between the planets, embarked on voyages lasting years. This vision is far from being a science fiction fantasy — instead, it is a concept which has been and continues to be seriously investigated and studied. How did this come to be? How is it that an idea as ancient as sailing has come to be proposed for the navigation of the solar system? To understand this, we must first go back to the seventeenth century and one of the greatest scientists of all time: Isaac Newton.

Newton thought of light as being a particle, a billiard ball that caromed around space carrying with it the essence of illumination. Common experience certainly upheld his opinion, and he pointed out to skeptics the sharpness of shadows on the straight borders of the light patches below his windows as proof. Only a particle, Newton reasoned, traveled in a line straight enough to cast this sort of pattern. But other theorists, Huygens, Snell and Young, were just not convinced. For one thing, light refracted (bent) when it passed from one liquid to another. A particle might slow down a bit, but it certainly would never bend. Another problem developed when the newly invented telescope consistently showed rings around a light source regardless of the reputation of the lensmaker. Such rings, a diffraction pattern of the primary image, could be explained most adequately if light were instead a wave and the rings created by the crests of the waves constructively reinforced one another.

The debate, "Wave or Particle?", raged on and embroiled the greatest scientists of history from Newton's time until 1906. So vocal did the question become in science that the arguments even spilled over into other fields. The German poet Goethe once wrote that Newton's analysis of light would "cripple Nature's heart." But 1906 was a benchmark year as the upstart Swiss patent clerk, Albert Einstein, began effectively to turn science around with his stunning insights into the physical processes of the universe. One of his publications in 1906, "Is the Energy of a Body Dependent Upon Its Energy Content?", spanning only a thousand words or so, concluded with an elegant formula relating the wave theory to the particle theory. Simply stated the equation meant that light could be either a wave or a particle, and it didn't matter because one was always related to the other mathematically.

> **"If the theory corresponds to fact, then radiation conveys inertia between the emitting and absorbing bodies."**
>
> **— Albert Einstein, 1906**

Beyond that, Einstein's work also suggested that any time a light beam reflected off a body, a force resulted exactly as if the light were a jet of water. Among the more astounding implications of this short paper, then, is the truth that the Sun quite literally beats down on the Earth, exerting a force against everything that its light strikes. Einstein eventually received a Nobel prize for this work (not, as some think, for his relativity theories). But scientists at the time remained dubious of such a seemingly illogical conclusion and conservatively withheld judgment until experimental proof might be forthcoming.

Imaginative thinkers needed no such proof to be stimulated into creativity. Konstantin Tsiolkovskii (the Goddard of Russia) for one, wrote a book proposing rocket ships which were propelled through space by the emission of light beams. From Einstein's paper, he concluded that by merely shining a light into empty space, a thrust results accelerating a rocket forward. (Without a doubt, even turning on a flashlight creates a force against the casing of the light, but the force is so vanishingly small — about one ten-trillionth of a pound — that measuring it escapes even the precision of today's science.) In the 1920s, though, when Tsiolkovskii performed some of his most interesting work, space flight remained beyond the comprehension of most laymen and his ideas died of neglect. Yet in the passing decades, experimenters gradually accumulated proofs of Einstein's more arcane ideas.

Then came World War II and the accompanying shock wave of development that forced science and technology into the modern era. Countless developments arose at a frantic pace and space flight no longer seemed so alien. The Germans had a V-2 rocket nearly perfected and they continually sought ways to use it to win the war. Scientists with the German army even considered launching giant mirrors into orbit — whether designed to light German towns at night or to focus light and incinerate English cities in a modern version of Archimedes' legendary weapon is still unclear. But in the plans tiny rockets are called for, designed to correct the orbital changes caused by solar radiation pressure. Though the Nazis sought by every means of propaganda to vilify and discredit Einstein because of his ethnic background, their scientists still paid him silent tribute by respecting his work in their designs.

At the close of the war, the V-2 reinvigorated the concept of space flight for the public. Still, even the most optimistic scientists knew the V-2 to be too crude even to penetrate space as deeply as the Moon. And the simple limitations of rocket design left Mars and Venus as inaccessible to man as ever. A more efficient and less costly method of propulsion was urgently needed. Researchers generated many novel concepts in the post-war years and in 1951, a scientist and writer named Carl Wiley advanced the idea of deploying a huge flat sail to reflect the Sun's radiation for propulsion.

Wiley envisioned a rocket such as the V-2 lofting a compact package of aluminum foil beyond the Earth's atmosphere. Once in orbit, the package would unfold to expose a surface area of 20,000 square feet or so and then a crew of men could steer it to any destination they desired in the solar system. By 1951, the plans for a very practical design were complete. He showed mathematically the size the sail needed to be, the thrust expected, flight times to some nearby planets, and many other intricate details of a device he called a "Solar Sail — the Clipper Ship of Space." Unfortunately, Wiley chose as a forum for his results the dime magazine *Astounding Science Fiction.* It was one of the sensationalistic pseudoscientific periodicals of those days feeding on the public's curiosity about the new cultivation of high technology. Sober-minded scientists paid little heed to these journals and even less to the claims of Carl Wiley.

Worse yet, Wiley used the pseudonym Russel Saunders whenever he wrote and so it appeared to the scientific community that he lacked the personal conviction to promote the Solar Sail.

So until the late 1950s, visions of a giant sheet of aluminum foil ferrying passengers to destinations around the solar system remained a poetic novelty. Occasionally, it was alluded to in science fiction stories but never seriously studied.

Then the chemistry department of the DuPont Corporation stumbled onto a new "space age" plastic it called mylar. Mylar turned out to be incredibly tough and resilient, yet it could easily be formed into sheets of extreme thinness, up to one-fortieth as thin as a dime. The most stringent

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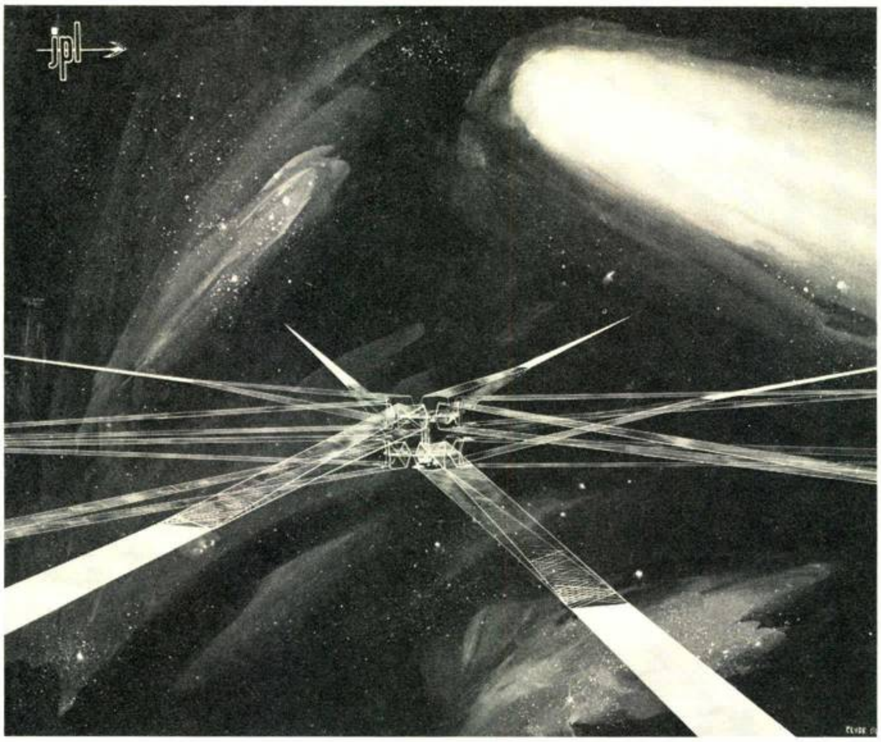

requirements for making a Solar Sail feasible were suddenly available in a single material.

With a small deposit of aluminum on one side to enhance its reflectivity and black oxide paint on the other to reject waste heat into space, mylar made even Wiley's sketches and calculations seem primitive. The real practicality of a Solar Sail became evident. In 1959 and 1960, and continuing for maybe another four years, scientists published serious volumes on how to design and fly a workable Sail. But the 1960s turned out to be lean years for suggesting new research. NASA, committed to the moon landing and dedicated to chemical propulsion, in the short term at least had no surplus cash to pass around. The Solar Sail, along with Solar Ion Propulsion and the NERVA Engine remained just curiosities.

A few researchers still tinkered with proposals after 1965, but only one — Richard McNeal — made any substantial new contribution. It dawned on McNeal one day that toilet paper manufacturers had already discovered a way to dispense large areas of a very thin material, and all he needed to do was to magnify the scale a bit, in this case to maybe a mere half-mile. A year later, in 1967, he revealed detailed plans for the "Solar Heliogyro." Basically, it consisted of a huge propellerlike device that spun to keep six blades in place, forced outward from rolls, by centrifugal force. McNeal's scheme eliminated much of the structure called for in the classic square Sail, even though his blade designs stretched out farther than nine football fields. Looking at the Heliogyro, it isn't difficult to guess McNeal's career at the time. He acted as a consultant to the helicopter industry.

After the introduction of the Heliogyro, McNeal worked out more sophisticated designs with blades as long as four or five kilometers. Worried that a spacecraft as large as this (unheard of in the pre-Shuttle days) might be grounded on account of some unforeseen design triviality, his 1967 analysis volumes are extremely extensive, perhaps the most complete prefabrication analysis ever attempted. Even with McNeal's work the Solar Sail simply remained a spacecraft in search of a purpose. The moon landing still stood two years in the future and NASA's role beyond that was highly problematic.

Another eight years passed, and then suddenly in 1975 a purpose for the Solar Sail was provided by the Advanced Projects group at the Jet Propulsion Laboratory. Halley's comet was due to stage its once-in-a-lifetime show again in 1985 and planetary researchers felt it would be extremely valuable to have a close-up look at it with an unmanned sampler. There was one big problem, though: Halley's Comet orbits the Sun in a retrograde direction (clockwise when looking down on the solar system from the north). In other words, it moves in a direction opposite to that all other planets follow. Because any space probe launched directly from the Earth goes in the same direction and with practically the same velocity as the Earth, a conventional spacecraft from here would pass the comet like one bullet might pass another. Taking a few leisurely snapshots in the fraction of a second of a rendezvous is like having a ten second vacation at the Grand Canyon. On the other hand, building a space vehicle large enough first to overcome the Earth's orbital velocity and then to be reaccelerated into a retrograde orbit, is (if not impossible) at least prohibitively expensive — that is, for any conventional propulsion system. The Solar Sail is far from ordinary for a number of reasons. It suddenly dawned on a group of orbital mechanists, such as Jerome Wright and C.W. Uphoff (both of JPL) among others, that a Solar Sail can be made to "crank" around the Sun.

To explain cranking, think of the Sail's orbit as being a hoop girdling the Sun. If the Sail is canted so that the force against it pushes up or down with respect to the eliptic plane, then the hoop rotates around an axis through the plane of the hoop and the Sun until it circles the Sun over its poles instead of on the equator. Allowed to go on long enough, the hoop continues to rotate until it is again at the equator — except now, the satellite is revolving around the Sun opposite to the way it started — a perfect retrograde orbit. Then, after some further refinement in its orbit, a Sail could chase Halley's Comet virtually forever transmitting photographs or even sampling data from the coma. An unexpected windfall of knowledge about the unchartered regions over the solar poles transmitted during the "cranking" alone justifies the mission.

A vigorous development program got underway at JPL and with the preliminary design hurdles out of the way, work proceeded swiftly. All too often, though, political decisions intrude on the ideas of scientists, and in the summer of 1977, NASA quietly withdrew funding for the Solar Sail in favor of a Solar Electric Propulsion System (SEPS) for the comet mission — which itself is also now in limbo.

Even without the Halley mission, though, destinations uniquely suited for the Sail still abound. But before listing them, a brief digression into the orbital mechanics of Solar Sail operation is required. First, let's look at the matter of round trips.

Flying away from the Sun — from the Earth to Mars, for instance — is fairly straightforward. Bundles of light quanta simply "blow" the Sail away from the Sun like a giant milkweed seed and it eventually spirals out to its destination.

(Remember that a satellite's true velocity is a combination of the Earth's velocity at launch and its propulsion velocity, so the final path it takes would appear to an observer outside of the solar system as a spiral.) Now, however, at Mars it would seem as if the payload would be stranded never able to fly back upsun (towards the Sun against the solar wind).

But a little knowledge of celestial mechanics reveals a way. As already pointed out, anything launched from the Earth has nearly the same speed with respect to the Sun as the Earth itself. Yet the Earth appears "weightless" to the Sun in exactly the same way an astronaut appears weightless to the Earth. That is, the gravitational attraction of the Sun is exactly counterbalanced by the centrifugal force of the revolving Earth.

As a spacecraft slows down, its centrifugal force is reduced and the gravitational force, now the strongest, pulls it inward. At the distance of Mars, a Sail traveling at the martian orbital velocity would be in a stable orbit. To make a return, all the clever astronaut need do is to direct the reflected light so that it subtracts from his orbital speed. Slowly the gravitational force of the Sun begins to outweigh the centrifugal force and the satellite coasts back toward the Sun intercepting the Earth somewhere along the way. Essentially, the same principle is used in returning manned capsules from orbit around the Earth today. When a retro rocket is fired, its tendency is to slow the spacecraft down and allow the Earth to pull its wayward offspring home.

Another common misconception is that the Sail is too slow for manned missions. Of course, the Sail doesn't quickly accelerate to huge velocities and then coast to its destination in the manner of a chemical rocket, so the total effect is much less dramatic. But the small thrust is constant and when allowed to act over a period of time, the effect quickly accumulates. For instance, a 10,000 square foot Solar Sail (about the size of an average supermarket parking lot) would leave the Space Shuttle with only a modest velocity. After a week of flight, its speed would have picked up to maybe 2500 miles an hour above that at launch. And after a month and a half, the velocities of a more traditional space capsule and a Solar Sail are identical.

So a quick trip to Mars might require 350 days instead of the 280 or so needed by chemical rockets. With a bigger Sail, the differential is even less and the best part is that with Solar Sail propulsion, fuel is used only for the initial boost into orbit — after that, all of the energy is provided free from the Sun.

Presently, it is estimated that a manned mission to Mars might cost the sponsor about $150 billion with today's chemical technology. Truthfully, a Solar Sail mission would cost about the same amount right now — far beyond the resources of any country's petty cash fund. The ultimate potential for the Sail in reducing costs, however, is enormous. What drives up the price currently is the lack of experience in deploying large flat structures in space and the problem of manufacturing mylar or its cousin, kapton, to the dimensions required. Both of these technicalities will vanish when the Sail reaches the sophistication enjoyed by today's liquid and solid propellant rockets. Then the true potential may be fully realized.

Dr. Gary A. Flandro of the University of Utah (who first conceived of the Grand Tour visit to the outer planets and is considered an expert in mission planning) is enthusiastic about the Sail's great

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flexibility.

"Imagine a spacecraft that can fly to any destination in the solar system, uses no natural resources for power, and can be flown again and again to a variety of destinations with no refitting at all," he says.

Indeed, once placed in orbit, the Sail need never be brought to the Earth's surface again. A returning Sail from Mars could be parked in orbit just outside of the Earth's atmosphere while a team of astronauts from the Space Shuttle patches a few of the holes and realuminizes the mylar. After a week of this, the same Sail is ready to be targeted to the inner solar system for a soil sample or maybe to the asteroid belt on a photographic reconnaissance, not costing the user the price of building a new spacecraft.

Jerome Wright, who has performed most of the research on the Solar Sail since 1970, sees many mission possibilities throughout the solar system. One of his favorite proposals is to use the Sail as an interplanetary shuttle. Trains of Sails could depart and return from the vicinity of the Earth on a periodic basis bringing back material from the asteroids or surface samples from the outer planets or maybe the rings of Saturn.

Trips to the inner solar system are even more attractive since the Sail performance increases with the inverse square of its distance from the Sun. In fact, a sample return flight from Mercury is likely to be the first use of a Solar Sail.

Yet, as with all new technology, before it can be made of benefit, a design must first be made workable. A host of technical problems remain to be solved. Unfolding ten to twenty thousand square feet of material thinner than the average garbage bag from a cannister smaller than a trash barrel is no mean engineering feat. As the 1980s open, though, the chances for trial and repeated trial afforded by the advent of the Space Shuttle will be available.

Where once designers were given only one chance for success, the Shuttle will allow the opportunity for correction that the complexity of the Solar Sail can exploit.

*Thomas Morgan*
Sunnyvale, CA

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## Listen to the Wandering Stars

For days now you've looked forward to tonight. You've studied and checked the charts, your scope is in perfect order, and your camera is loaded with the right film. You eagerly await sunset so that your nebula, comet, nova, or whatever will be visible.

As you leave the house the sky darkens, the stars fade to obscurity. You lift your face to the heavens and ..... rain dances merrily on your face. There are a few things you can do: swear, get a wet telescope and a cold, go in and watch the tube.

Or you can listen to the wandering stars.

You won't need your own personal radio telescope, nor a superduper professional listening device. All that's really required is a record player and a recording of Gustav Holst's *The Planets*.

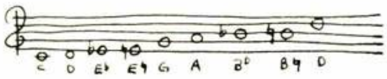
Holst (1874-1934), an English composer more atuned to astrology than astronomy, wrote *The Planets* in 1914-1916, and it is one of the few symphonic pieces written in this century specifically on a celestial theme. As such, it's part of a long tradition linking astronomy and music.

Ever since the birth of astronomy, there have been persistent efforts made to ally the two. Pythagoras speculated on the "harmony of the spheres." Pliny later ascribed the following Pythagorean musical intervals to the planets:

Earth to Moon......a whole tone
Moon to Mercury...a semitone
Mercury to Venus...a semitone
Venus to Sun.......a minor third
Sun to Mars........a whole tone
Mars to Jupiter .....a semitone
Jupiter to Saturn....a semitone
Saturn to stars.......a minor third.

A whole tone is the aural distance on a piano from, say, one white key to the next white one over an intervening black key, or from one black key to the next over an intervening white key. A semitone is the distance from a white key to a neighboring black one, or from one white key to another provided they are adjacent. A minor third is the distance of a whole tone plus a semitone: C to E flat, D to F, E to G, and so on.

Using the tone intervals ascribed to Pythagoras by Pliny, we ought to be hearing the following scale all the time:



What happened after the notes reached the top is a mystery. Did they go back down to C, did they start all over again, or were they all sounded simultaneously? We don't know.

Centuries later, Johannes Kepler (1571-1630) used the idea of harmony and celestial music in working out the orbits of the planets. According to him, each planet played a certain tune. Saturn, the most distant, played the lowest notes, while Mercury, being closest to the Sun, played the highest. (Kepler was a devout Copernican!)

Kepler's music isn't far from being music, if each planet is heard separately, but together they produce raw dissonance. Saturn plays the first three notes of a G major scale, while Jupiter plays the third, fourth and fifth notes of the same scale an octave higher. Mars sounds the first five notes of an F major scale. Earth and Venus are neither here nor there, musically speaking, while Mercury, starting on a C, goes all the way up to E and descends through the C major triad. Played very high, Mercury sounds scintillating and brilliant.

Anyone interested in how all this might really sound may be interested in a record recently issued on which the notes have been played by a computer-driven synthesizer. For details, write to: Prof. Willie Ruff, School of Music, Yale University, New Haven, CT 06520.

But where Kepler's music fails, Holst's triumphs. Instead of assigning simple scales or keys to each planet, Holst wrote symphonic movements. And where Kepler kept his ideas simple, Holst more ambitiously attempted to portray the astrological meaning of each planet:

Mars, the bringer of war
Venus, the bringer of peace
Mercury, the winged messenger
Jupiter, the bringer of jollity
Saturn, the bringer of old age
Uranus, the magician
Neptune, the mystic.

Each planet is characterized by the human passions it is said to influence. Holst's "pet vice," as he called it, was casting horoscopes, yet as it turned out they had little to do with *The Planets*. After he had taken his initial impulse from astrology, the music developed on its own.

World War I broke out just after the first sketch for "Mars" was finished. That autumn he wrote "Jupiter" and "Venus," and in the following year "Saturn," "Uranus," and "Neptune." "Mercury" was the last to be composed; that movement and the complete orchestration were finished in 1916. Pluto, by the way, wasn't included for the simple reason that it hadn't yet been discovered — that had to wait until 1930.

Holst's music has never collected a wide following, though in the last few years it has been more often played, perhaps because of *The Planets'* popularity. Ten years ago there were only a couple of recordings available, now there are 15 or more, the newer ones having incredible sonics.

Holst was an original. He wrote movie music long before movies had sound. *The Planets* is grand visual music on a gut level. Film composers have copied his style, intentionally or not, whenever the action calls for martial music, and their model, "Mars, the bringer of war," is perhaps the best of the seven movements. Without doubt, it is one of the most visually dramatic pieces of music to come from the pen of a 20th century composer.

Of course, the problem with music is describing it. If you're experienced enough, you can read a score and "hear" it, but most of us need a performance. Even so, "Mars" deserves some description — its very power forces a reaction.

The movement is one of incessant rhythm, the same 5/4 feeling that made the *Mission: Impossible* theme so successful. The atmosphere is demonic: death, destruction, and tragedy dominate. One reviewer noted the god of war's "brutal and stupid power," which seems to win out over all.

The ruthless deity appears to stride over fields strewn with bodies: Mars stalks the world. Waves of battle ebb and flow. Finally, utter defeat is shown as all motion ceases. Mars stands and surveys the carnage he has wrought. Satisfied at the outcome, he and his two companions, Phobos and Deimos (fear and panic), move quickly on to the next field of conquest. Barrenness and death are all that remain.

Some will hear this piece and see other things. With no written script, each will find a personal image. I have mentioned my picture, not Holst's. (Whatever he envisioned is lost, for he wrote no program to follow the music.)

"Mars" is followed by peaceful "Venus," moving serenely in total emotional opposition to it. "Mercury" comes next and literally flies past the listener as the music skips from one instrument to the next.

"Jupiter," the middle movement, is a round, robust section in which parts sound like English country dances, others like folk tunes, all orchestrated on an immense scale. Lethargy and sloth are typified by "Saturn" as the music, remaining in the low registers, portrays old age.

Yet the music breaks out again when "Uranus," the magician, plays musical tricks on the listener as the opening phrase keeps reappearing throughout the section, sometimes faster, sometimes slower, always at unexpected moments.

"Neptune" returns us to the ongoing rhythm of the "Mars" section, but here there is a feeling of eternity and mysticism in place of bloody warfare. In it a women's chorus sings no words, just sounds, evoking a totally unearthly feeling, a suggestion of the deep unknown. The movement and the whole *Planets* suite ends as the final two chords echo and repeat until, as Holst noted in the score, "the sound is lost in the distance."

The next time the heavens rain on your celestial parade, don't curse your fate or settle into a somnolent mindlessness. Thumb your nose at the clouds, close your eyes, and let your ears discover and explore the wandering stars of Gustav Holst's *The Planets.*

*Aaron Isquith*
New York, NY

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sky almanac

# parade of the planets

The year commences with great offerings for planet-watchers: only Mercury is out of sight and the other planets present themselves one by one throughout the night. Venus is visible in the early evening, Jupiter and Mars an hour or two later, and Saturn by midnight. Uranus rises in the early morning, and Neptune follows just before dawn. What more could you ask for?

### Mercury

The Sun's closest planet is no slouch: last month it was favorably placed in the morning sky; by the 21st of this month, it'll reach superior conjunction, at which time it will lie on the opposite side of the Sun from us. Out of sight for January, Mercury will be well positioned for observing during most of February.

## February Previews

1 Full moon
3 Moon - Jupiter conjunction
Moon - Mars conjunction
4 Moon - Saturn conjunction
5 Moon at apogee
9 Last quarter moon
16 New moon; total solar eclipse (Africa and India)
17 Moon at perigee
Mercury 2° north of Moon
19 Venus 4° north of Moon
Mercury at greatest eastern elongation
23 First quarter moon
24 Jupiter at opposition
25 Mars at opposition
26 Mars nearest Earth

---

The two big highlights for February are the back-to-back oppositions of Jupiter and Mars. Sky watchers will be hard put deciding which planet to devote the more time to. In addition, the elongation of Mercury will bring it into view and place it in the western sky below Venus.

### Venus

Lovely Venus is now becoming brighter and brighter as it climbs higher each night out of the haze in the southwestern sky. During January, the brilliant planet will gain 10° of elevation while moving the same distance northward along the horizon.

In a telescope, Venus looks decidedly gibbous, but is narrowing toward the half-lit phase: on the 1st, it will be 85% lit; on the 31st, 78%. At the same time, its apparent size is also growing, from 12.5 seconds of arc to 14.3. Venus will continue to increase its apparent size until it passes through inferior conjunction this summer, by which time it'll look over four times larger than now.

### Earth

On January 3rd, at $15^h$ UT, the Earth will be at its closest to the Sun. This point in our orbit is called perihelion, and the distance will be 147,093,000 kilometers (or 91,198,000 miles).

### Moon

On the evening and night of the 26th-27th, the 9-day-old Moon will be passing through the Hyades Star Cluster occulting many stars on its way, including Aldebaran. The disappearances will be on the bright side of the Moon; reappearances will be from behind the dark side. Since several cluster members will be occulted, there'll be activity going on no matter what time you go out.

### Mars

Mars is in Leo during January and at midmonth will be rising around 8 p.m. Having passed Jupiter last month, Mars will progress eastward until the 17th of January when it will lie 6° to the northeast of Jupiter. There it'll halt and begin retrograde (westward) motion, passing 3° north of Jupiter in late February.

The retrograde motion that all planets more distant from the Sun than Earth show on occasion will be demonstrated strikingly this spring, as Mars (along with Jupiter and Saturn) slows to a halt, loops backward, and then recommences direct motion again. Let the star Regulus in Leo serve as the benchmark for your observations, visual or photographic. (See Gazer's Gazette for more on Mars.)

### Jupiter

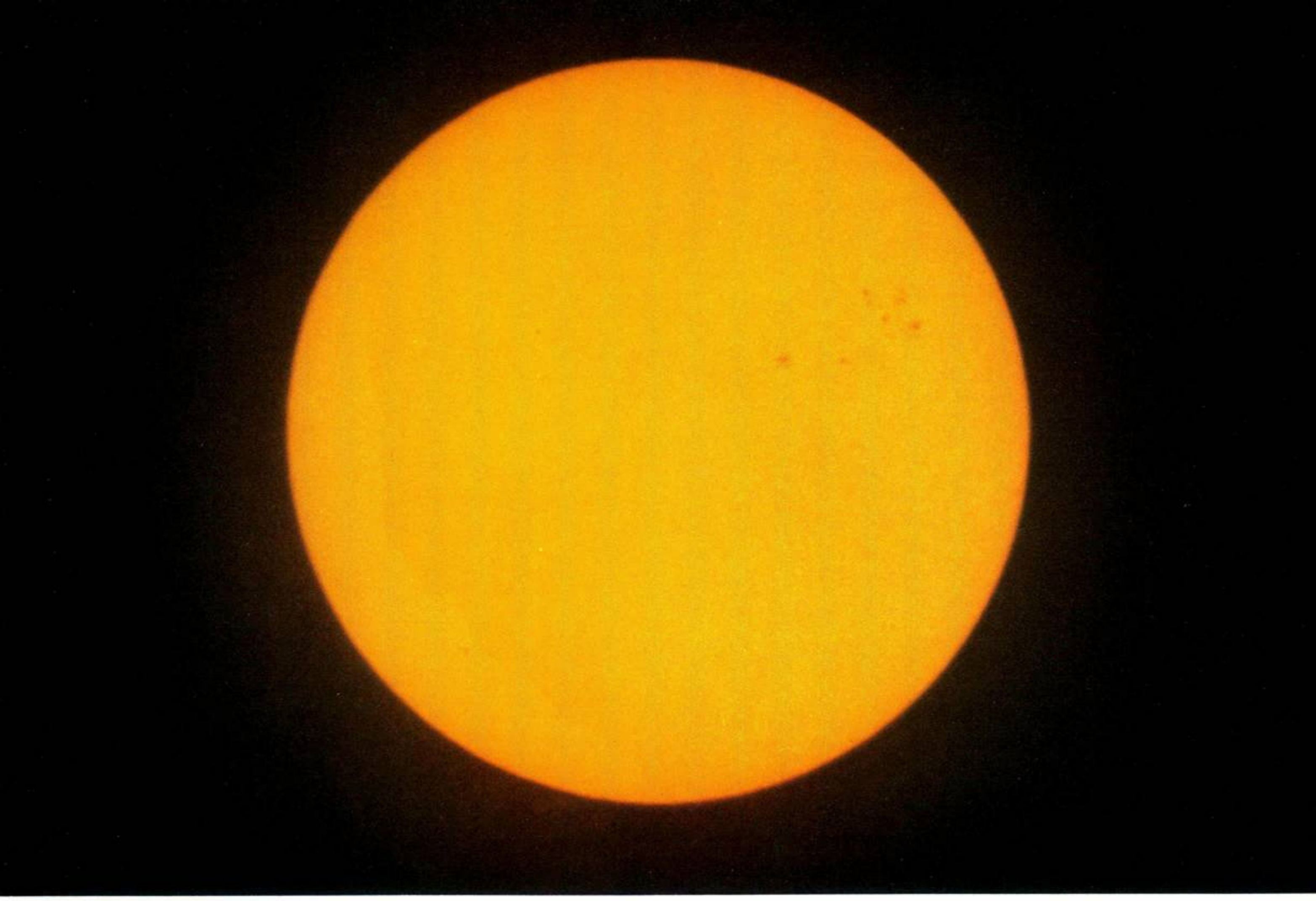
Both Mars and Jupiter arrive at opposition less than 24 hours apart late in February. Jupiter (also in Leo and likewise rising at midmonth around 8 p.m.) is now ideally placed for observation, so make the most of it.

If you're new to Jupiter-gazing, you might be wondering why you can't see much more on its disk than a couple of vague grey markings. Where'd all that color and detail go? The bland appearance is mainly the result of Jupiter's lack of contrast and your inexperience.

Despite the impression left by Voyager's contrast-enhanced photos, Jupiter's cloud features are subtle in their shading. The colors glow palely and are understated. It's only through familiarity with the telescopic appearance that you begin to discern color where it formerly seemed absent and details that used to pass unperceived. The best advice is to keep at it and watch how soon features begin to appear for you.

### Saturn

Saturn is in western Virgo, thus it is a late evening object. Although it rises *around 9:30 p.m. or so, you'll need to* allow it a further hour or more to climb out of the region obscured by houses



and trees. For telescopic views, this also means your line of sight won't be through the thick, unsteady air at low altitudes.

On January 2nd, Saturn's rings will be their widest open (1.7°) until late this coming August. But because the Sun is on the other (southern) side of the rings, they are virtually invisible.

Inevitably this means the spectacle is lessened, since Saturn's chief attraction for most people is the ring system. With the rings gone from sight, all that's left is a distinctly oval ball less than half Jupiter's size with far fewer markings. You'll have to look very carefully to pick out more than a couple of bands, though here again familiarity will do a lot to bring out features presently unseen.

Since we are looking almost in the plane of Saturn's equator, we have a view of its satellite system similar to what we always get with Jupiter. Look for Titan, the brightest of them, at western elongation from the planet on the 1st and 17th of January and at eastern elongation on the 9th and 25th. Very late on the nights of the 12th-13th and the 28th-29th, Titan will cross the disk of Saturn, preceded by its shadow. Like many similar events in the jovian system, these satellite and shadow transits are fascinating. Use as high a power on your telescope as the seeing conditions permit.

### Uranus

Uranus is in the easternmost parts of Libra, about 10° away from Antares. It is a morning object and not a very easy one at that. During January, you can try sweeping up from Antares, or locate three 6th magnitude stars in Libra — Zeta ($\zeta$), 34, and 32 Librae — and search 2° south of the flat triangle formed by the three.

Once seen, you'll have no trouble locating it during the next four months as Uranus will remain "below" the three stars until May. Observers having a scope with setting circles can use the position in Planet Finder; those using binoculars or an alt-azimuth mount will find Zeta, 34, and 32 Librae near Gamma ($\gamma$) on the southeastern side of Libra's diamond asterism. (Look at a May Star Dome to find the constellation.)

### Neptune

This dim, small planet will be found in the predawn sky in eastern Ophiuchus about a degree southeast of 4.5 magnitude Xi ($\xi$) Ophiuchi. You'll do best to wait until mid-January to hunt for it, since its elevation 45 minutes before sunrise is only 6° on the 1st. But on the 15th, it will be 14° high in the southeast at the same time

**The golden orb of the Sun, sprinkled with spots, glows from this photo by Jiri Krakora. Using a 6" Schmidt-Cassegrain telescope, he exposed Vericolor II for 1/60 second, push-processing it to 400 ASA.**

### Lunar Phases

Full moon: Jan. 2 at 09:02 UT in Gemini. Last quarter: Jan. 10 at 11:49 UT in Virgo. New moon: Jan. 17 at 21:19 UT in Sagittarius. First quarter: Jan. 24 at 13:58 UT in Cetus. Apogee: Jan. 8 at $08^h$ UT; perigee: Jan. 20 at $02^h$ UT.

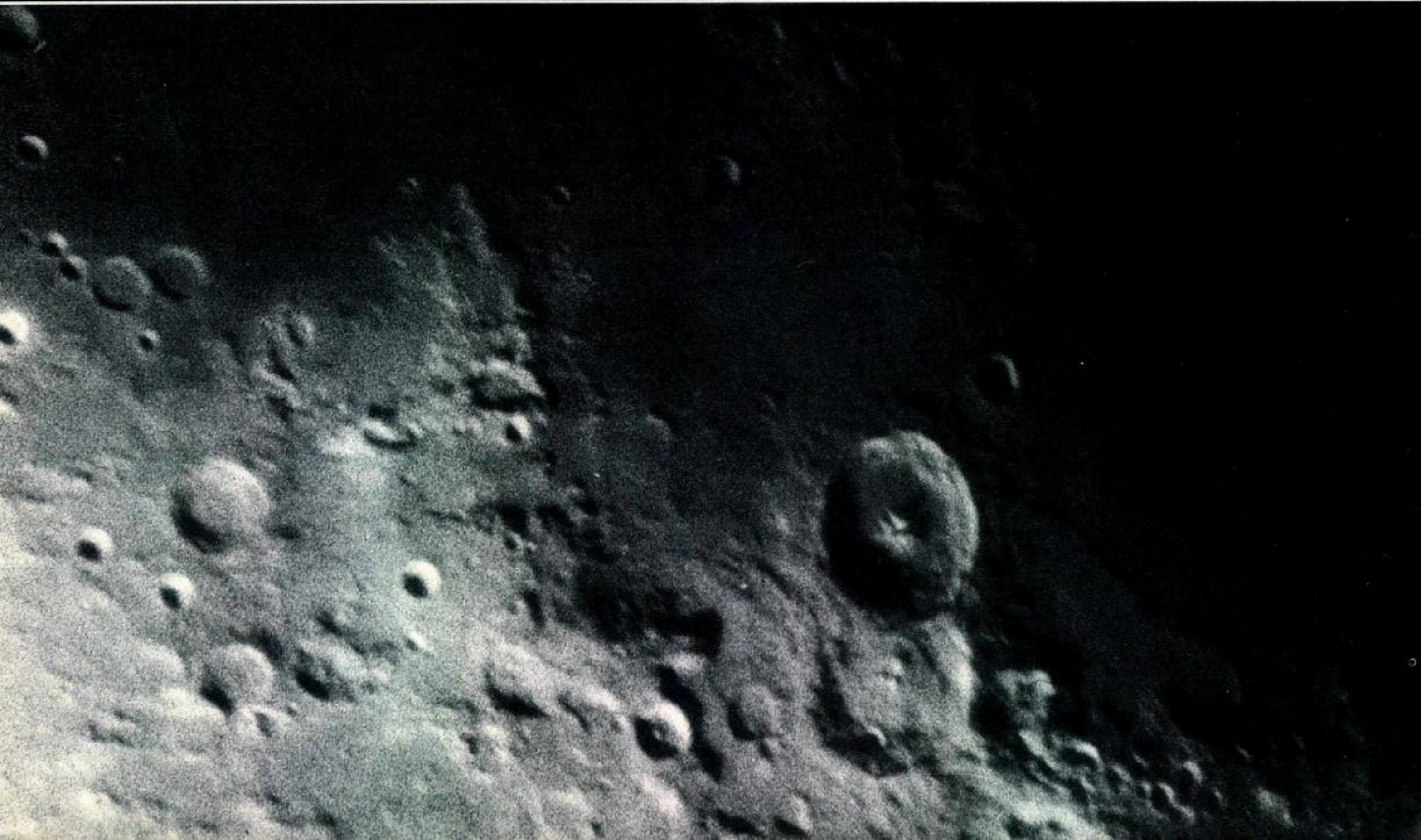
### Universal Time

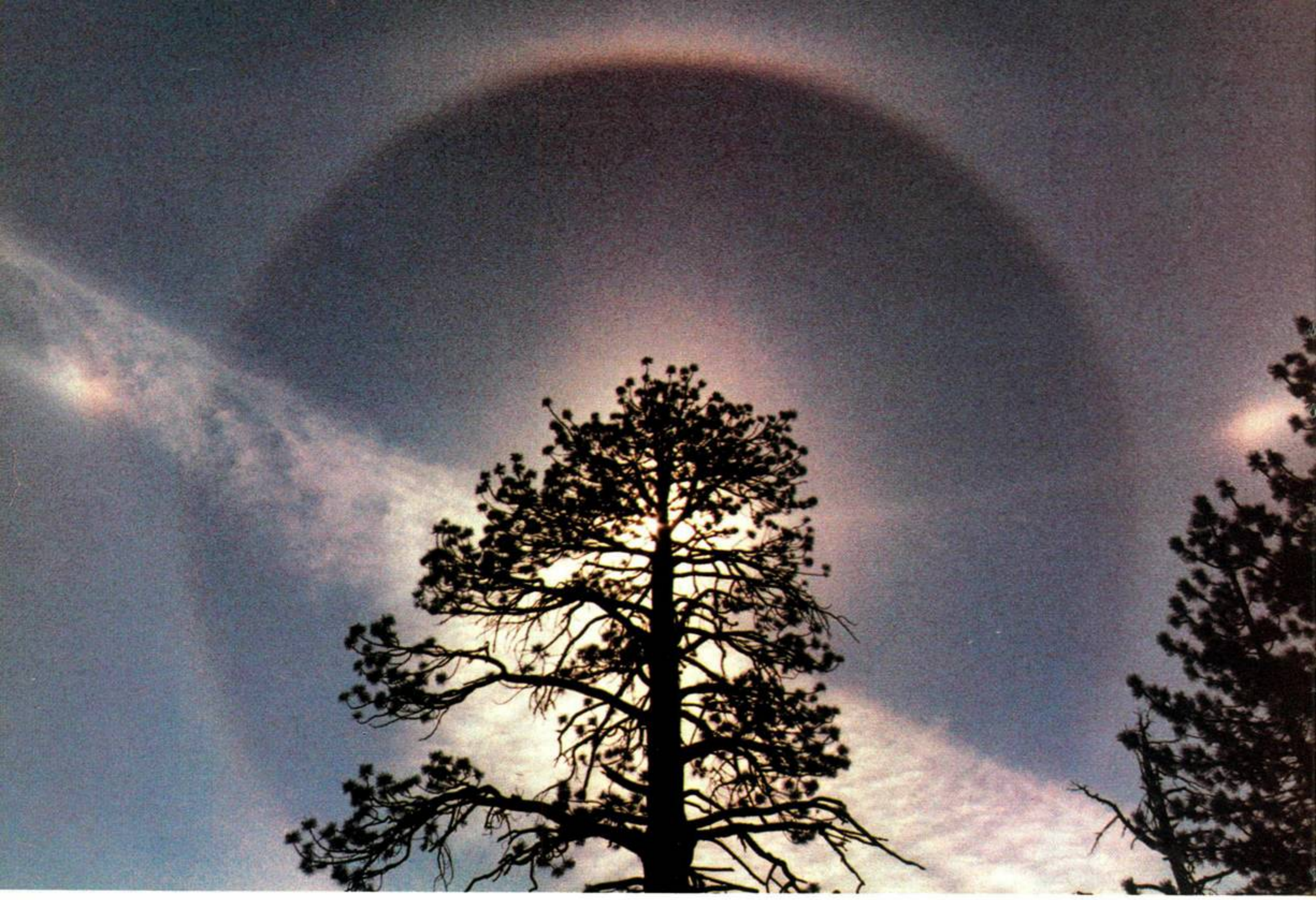
Astronomers the world over use an unambiguous system of time reckoning based on a 24 hour clock, called Universal Time (UT). Times given in Sky Almanac are in UT unless noted otherwise. To convert UT into your local standard time, subtract the following number of hours for each time zone: EST, 5; CST, 6; MST, 7; PST, 8; Alaska and Hawaii, 10. For example, if an event is to happen at 03:00 UT on Jan. 2, then the time in EST would be 10 p.m. Jan. 1. Likewise, 03:00 UT on March 5 becomes, in PST, 7 p.m. on March 4.

Dark skies + ordinary equipment = splendid photography — but only if you do everything right. This grand view of Scorpius and the southern Milky Way was taken on Tri-X with a 50 mm lens at f/2.8 in a 15 minute exposure by Chris Smith.

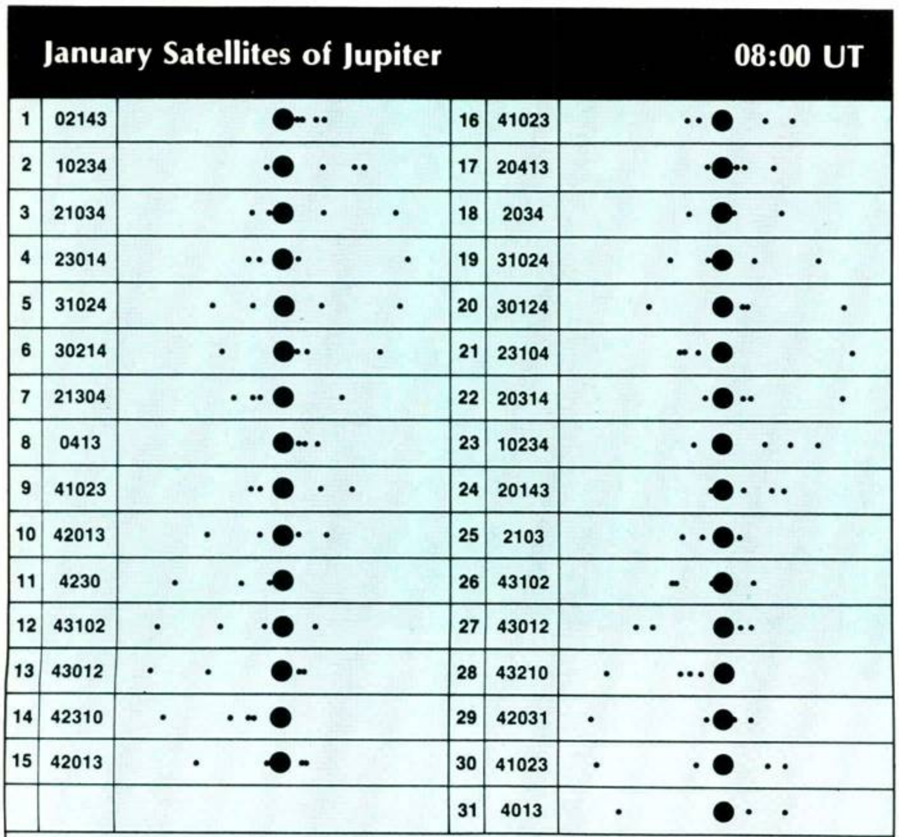
At the end of September 1979, Jupiter passed Regulus; these three photos cover a four-day period from the 24th (left) to the 27th (right). Jim Haklar's equipment was a 135 mm lens and Tri-X. Exposures ranged from 8 to 16 seconds.

A low sun angle brings out the details in the Theophilus region of the Moon. Local time is late afternoon. R.E. Erickson's photo was taken through a 6″ f/13 refractor with eyepiece projection onto Tri-X, ¼-second exposure.





**Imaginative use of foreground objects can turn interesting shots into real stunners. Don Donalson was in Yosemite National Park last July when he snapped this photo of a solar halo and sun dogs. Film was 400 ASA.**



**January Satellites of Jupiter** **08:00 UT**

| | |
|---|---|
| 1 | 02143 |
| 2 | 10234 |
| 3 | 21034 |
| 4 | 23014 |
| 5 | 31024 |
| 6 | 30214 |
| 7 | 21304 |
| 8 | 0413 |
| 9 | 41023 |
| 10 | 42013 |
| 11 | 4230 |
| 12 | 43102 |
| 13 | 43012 |
| 14 | 42310 |
| 15 | 42013 |
| 16 | 41023 |
| 17 | 20413 |
| 18 | 2034 |
| 19 | 31024 |
| 20 | 30124 |
| 21 | 23104 |
| 22 | 20314 |
| 23 | 10234 |
| 24 | 20143 |
| 25 | 2103 |
| 26 | 43102 |
| 27 | 43012 |
| 28 | 43210 |
| 29 | 42031 |
| 30 | 41023 |
| 31 | 4013 |

**Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4**
**(South is at top, matching the view in a telescope.)**

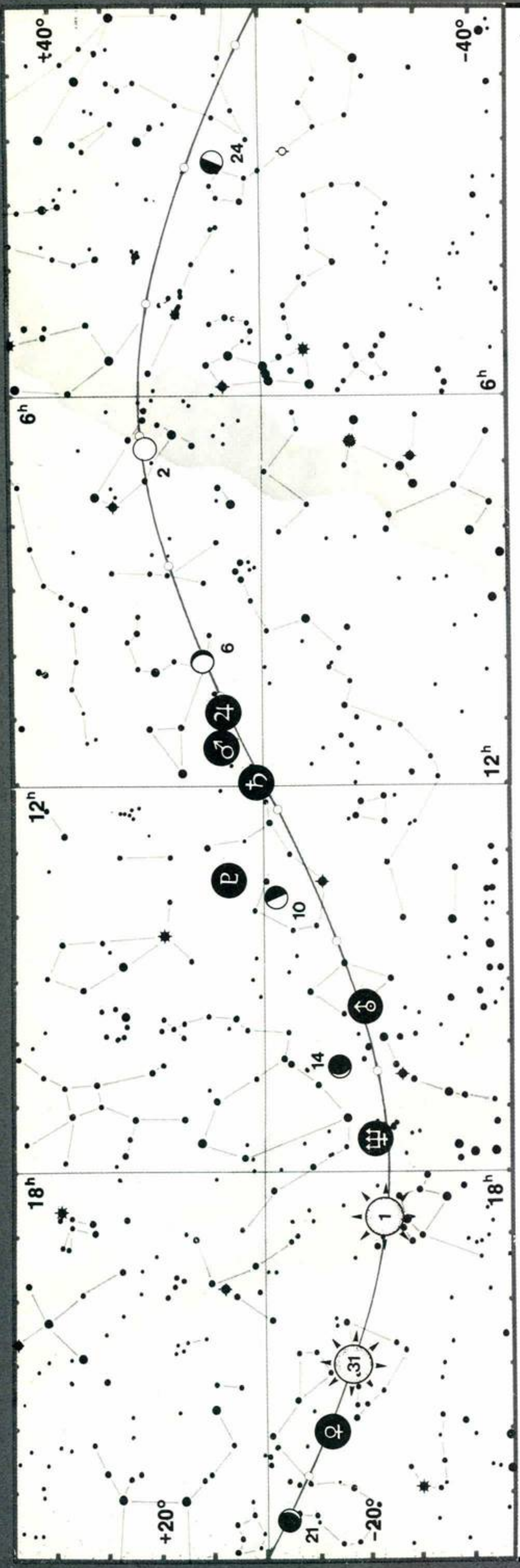
of day, and by the 31st, the elevation will amount to 20° (in azimuth 145°). When you are sweeping for it, look for the "star" with the discernible disk.

### Meteors

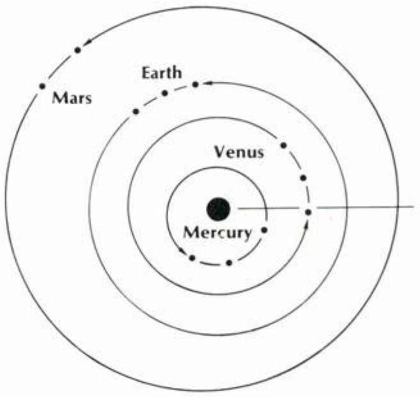
January can claim only one shower of any size, the Quadrantids. Coming from a part of the sky near the Bootes-Draco-Hercules border and noted for many faint blue meteors, the Quads normally benefit from a relatively dark observing site.

Peaking at $10^h$ UT on the morning of the 4th (that's predawn hours, same day, in North America), the usual single observer rate is about 40/hour. Unfortunately the Moon will be full and its bright light will wash out many of the shower members, especially if the ground cover in your area is snow. (Why the oddball name? The old constellation Quadrans Muralis was absorbed by Bootes, Hercules, and *Draco and so disappeared,* but not before it gave its name to this meteor shower.)

# Planet Finder January 1980

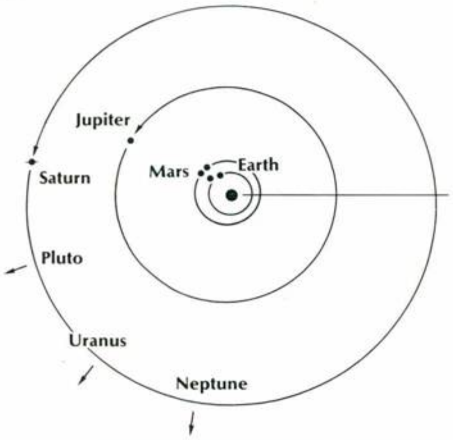

+40°
-40°
6h
6h
12h
12h
18h
18h
+20°
-20°
24
2
6
10
14
1
31
21
♃
♂
♄
♇
⛢
♆
♀

## The Planets in Their Courses


Earth
Mars
Venus
Mercury

The positions of Mercury, Venus, Earth, and Mars in their orbits are shown for the beginning, middle, and end of the month. (Mars for the beginning and end only.) The vernal equinox is the line at right.

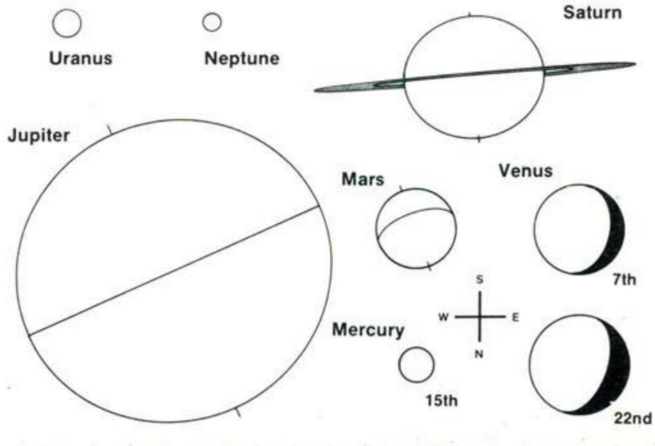
The orbits of Earth, Mars, Jupiter and Saturn are shown at right. Earth and Mars' positions are for the first and last of the month; Jupiter and Saturn for midmonth. The outermost planets' directions are indicated.


Jupiter
Saturn
Mars
Earth
Pluto
Uranus
Neptune

## Positional Data

| Planet | | Date | R.A. (1980.1) | Dec. | Mag. | Distance (AU) from Earth | Distance (AU) from Sun |
|---|---|---|---|---|---|---|---|
| **Mercury** | ☿ | 10 | $18^h52.5^m$ | -24°20.3′ | -0.6 | 1.42 | 0.46 |
| | | 20 | $20^h02.8^m$ | -22°29.9′ | -0.9 | 1.42 | 0.44 |
| | | 30 | $21^h13.4^m$ | -18°08.6′ | -1.0 | 1.36 | 0.39 |
| **Venus** | ♀ | 10 | $21^h41.6^m$ | -15°39.3′ | -3.4 | 1.30 | 0.73 |
| | | 30 | $23^h13.3^m$ | -6°15.3′ | -3.5 | 1.18 | 0.72 |
| **Mars** | ♂ | 15 | $11^h11.6^m$ | 9°04.9′ | -0.1 | 0.86 | 1.66 |
| **Jupiter** | ♃ | 15 | $10^h46.6^m$ | 9°03.3′ | -1.9 | 4.65 | 5.38 |
| **Saturn** | ♄ | 15 | $11^h52.4^m$ | 3°15.2′ | +1.1 | 8.94 | 9.42 |
| **Uranus** | ⛢ | 15 | $15^h29.5^m$ | -18°39.7′ | 5.9 | 19.21 | 18.73 |
| **Neptune** | ♆ | 15 | $17^h22.9^m$ | -21°49.2′ | 7.9 | 31.10 | 30.28 |
| **Pluto** | ♇ | 15 | $13^h44.4^m$ | 7°37.1′ | 14.0 | 30.12 | 30.18 |

## Telescope View


Uranus
Neptune
Saturn
Jupiter
Mars
Venus
7th
Mercury
15th
22nd
S
W
E
N

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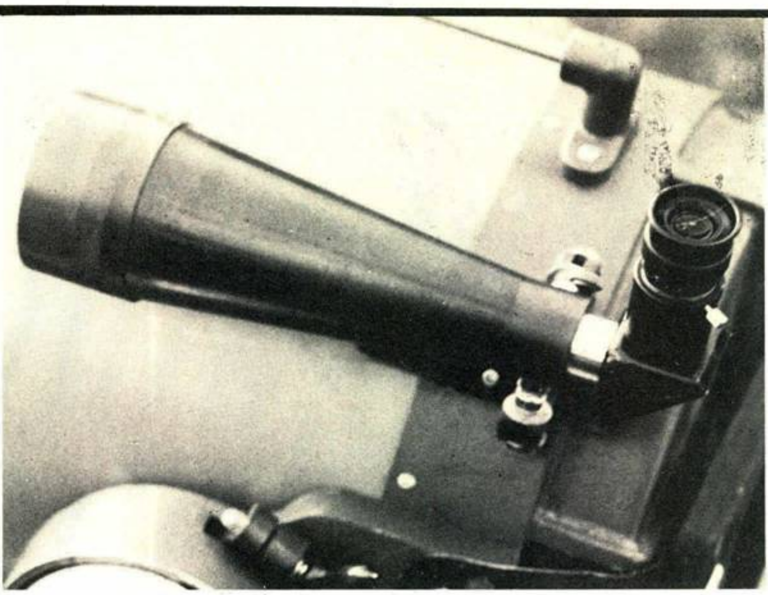

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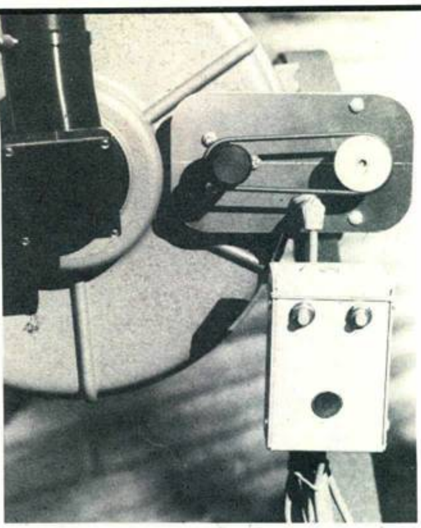

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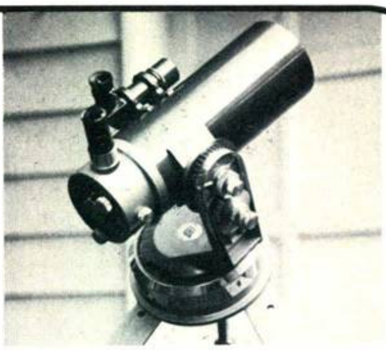

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gazer's
gazette

# observing the red planet

### by Charles Capen

The red planet. *Mars.* Its very name fires the imagination. Who hasn't pictured for himself that cold, planetwide desert of broken stones, ruffled by a thin icy wind? Viking has made Mars familiar to us in a vicarious, second-hand way, but it's an alien place all the same.

Yet this is a dynamic world with the most earthlike characteristics of any planet but our own: four seasons, its own climate, changeable weather, storm clouds and howling winds, polar ice caps, and a wide assortment of surface features. Its active atmosphere generates many exciting changes visible to observers on Earth with moderate-size telescopes.

## The Martian Environment

A day on Mars (called a *sol*) is about 40 minutes longer than a day on Earth, with the result that the planet rotates through only 350° of longitude in 24 hours. As you observe through your telescope this means that the planet appears to "back up" from night to night, making an illusory reverse rotation in about 36 days. Therefore, any given martian region can be observed for an 8 to 20 day period at intervals of about 36 (terrestrial ) days.

Both Mars and Earth have four comparable seasons because their axes of rotation are each tilted at about the same angle to their respective orbital planes. Mars' axial tilt is 25.2° as compared to 23.5° for Earth. However, the axis of Mars doesn't aim at our North Star, but is displaced about 40° towards Alpha Cygni.

Because Mars' axis tilts in a different direction, the martian seasons are 85° out of step with ours, or about one season in advance. Consequently, when you make observations of Mars this winter and spring, you'll be looking at spring and summer, respectively, in the martian northern hemisphere.

At this time of the martian year, many seasonal variations are happening on the ruddy disk. Mars' year lasts nearly twice ours, so the seasons are similarly longer. But while Earth's are nearly equal in duration, the length of Mars' seasons varies by as much as 51 sols because of the orbit's greater eccentricity.

The martian year lasts 687 Earth days, or just 43 days short of two terrestrial cycles. Every two years and 50 days, on average, Mars arrives at opposition, a time when the Earth is passing it in its orbit. This places Mars opposite the Sun in the sky, rising in the east as the Sun sets. Each opposition occurs in a different part of the martian orbit, with the opposition points rotating in a counterclockwise direction around the Sun. A complete cycle of oppositions takes about 15.8 years.

## When is Viewing Best?

Oppositions provide the best chance for telescopic observations since the planet is then visible the whole night through. February 25th marks the date of the 1980 opposition, and every telescope owner should start preparing to grab the opportunity.

All this winter and spring, Mars' placement will be good as its position will lie well north of the celestial equator. For northern hemisphere observers, this puts the planet high in the sky, where seeing conditions are best.

Unfortunately, not all oppositions are equal, and the 1980 one comes at a time when the planet is about as far from us as it can be. Such oppositions are called *aphelic* ones (because Mars is at or close to aphelion, or its farthest distance from the Sun), and the result is a smallish-looking Mars in the telescope. With an apparent disk diameter of 13.8 arc-seconds and a distance of 63 million miles, Mars hasn't looked this small at opposition since 1948.

## When to Observe

It's worthwhile starting your observations when Mars' apparent diameter is 6 seconds of arc or larger. On page 42, there's a graph showing how the martian disk changes size over the months. It shows that Mars will be 6 seconds or larger between November 1979 and mid-July 1980.

Observing Mars can mean anything from visual drawings and photography to photometry and micrometry of salient features. What you do is limited only by the size of your telescope, which mostly determines the resolution you'll get, and your available equipment.

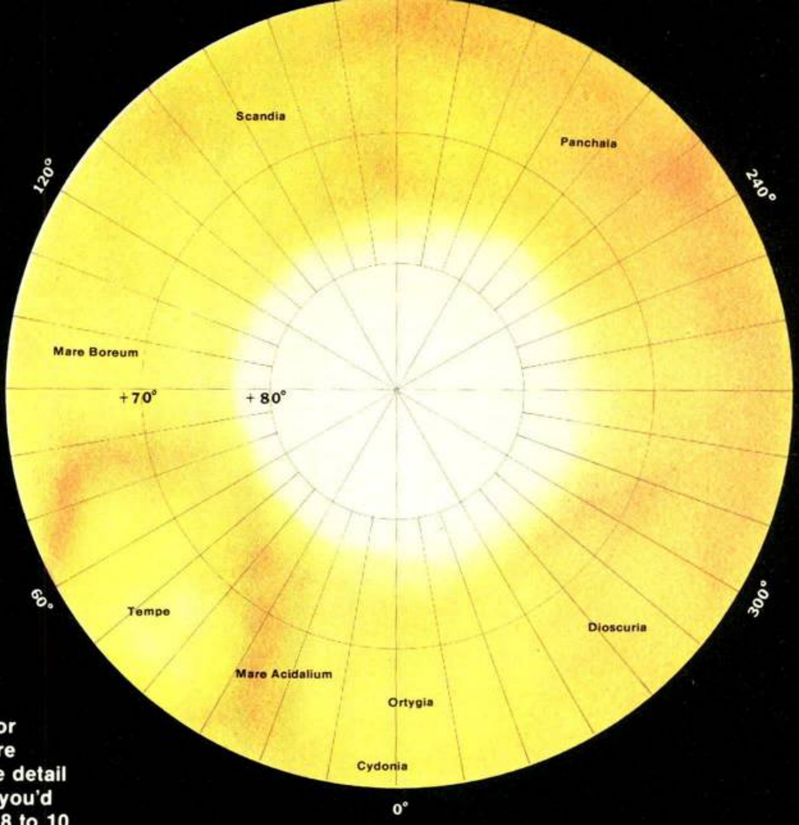
For example, observers with 3.5 to 6-inch telescopes can look for large surface features and contrast changes, bright clouds, limb hazes, and coarse polar cap details. Apart from a range of good eyepieces, the next most useful accessories are some color filters (red, green, blue, and violet).

Telescopes with apertures of 8 to 12 inches will enable you to see conspicuous surface features within several months of opposition. Also, color filters will bring out seasonal variations of the light and dark features, white clouds, and bright frost patches.

## Try Photography, Too

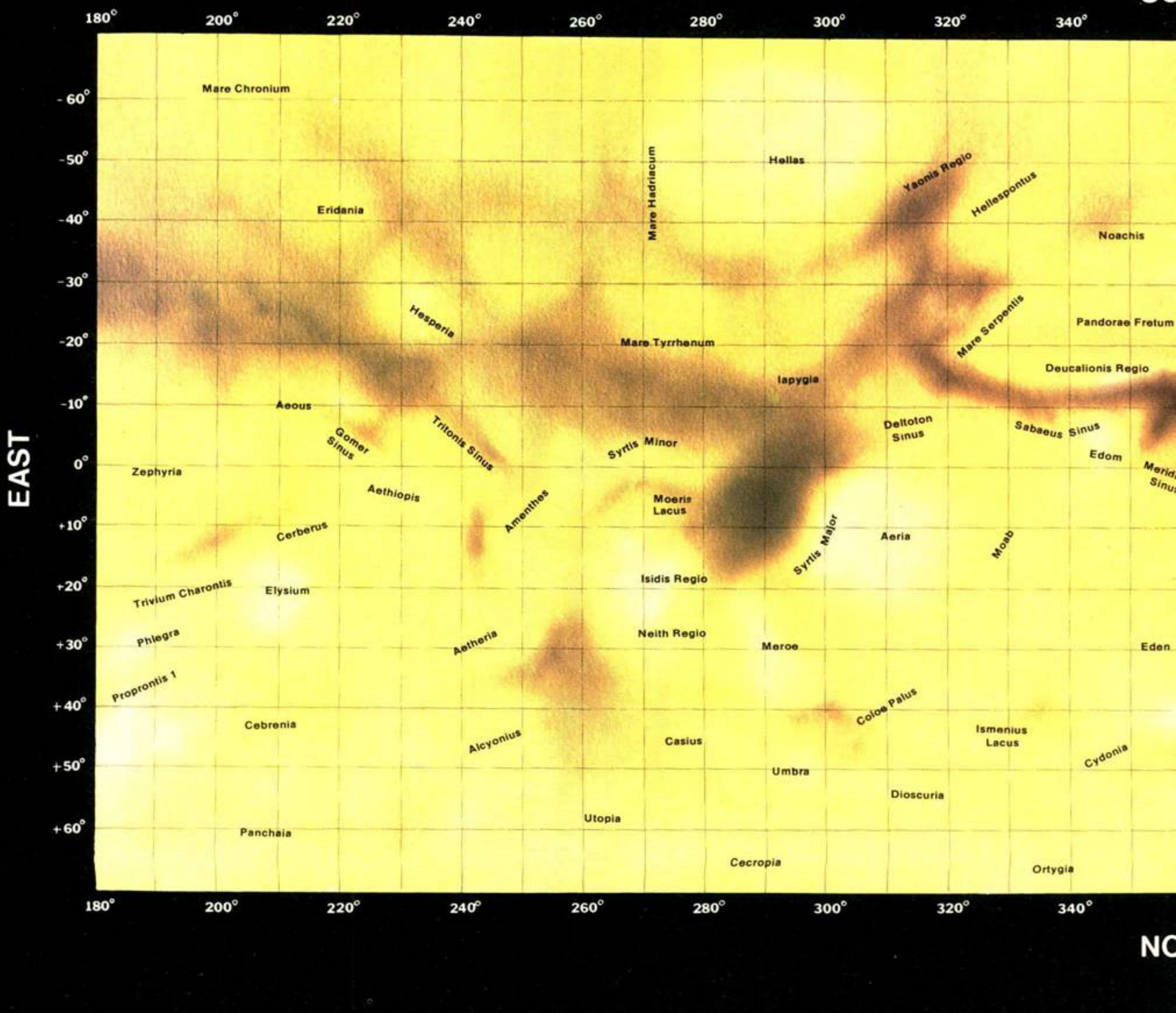
Good photography is possible when the apparent disk exceeds 10 arc-seconds' diameter (January until late April 1980). As Mars' disk is always small, you'll need to use eyepiece projection or a Barlow lens in your system to get a film image that's at least 3 to 4 mm in diameter. The problem

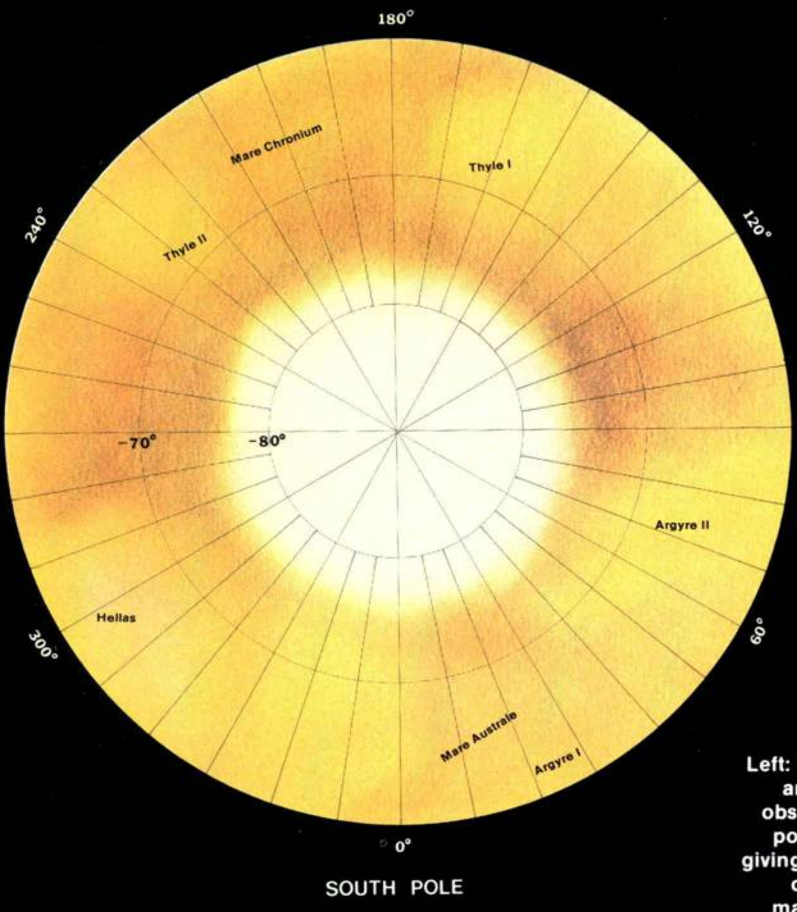
**Your best chance to look at Mars until March 1982 comes late next month when the tiny red planet arrives at opposition. The photo shows what an experienced observer might expect to see with an 8" to 10" telescope on a night of superb seeing. Photo by author.**


Scandia
Panchaia
120°
240°
Mare Boreum
+70°
+80°
60°
300°
Tempe
Dioscuria
Mare Acidalium
Ortygia
Cydonia
0°

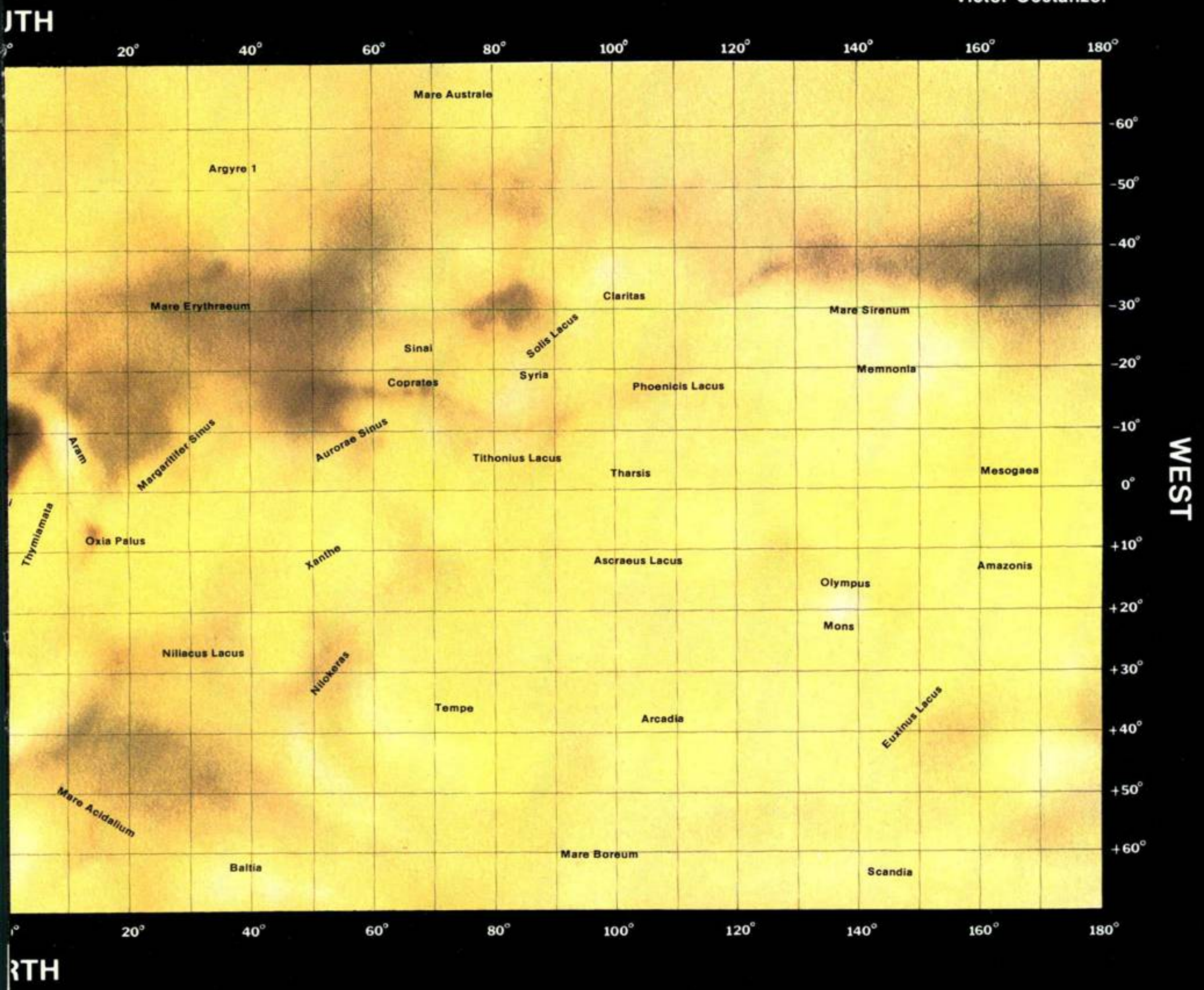
NORTH POLE

**Below: most of the major features of the planet are shown on this map. The detail depicted is about what you'd see with a telescope of 8 to 10 inches aperture. The view is inverted (south is at top), so it corresponds to the way Mars actually looks in the eyepiece.**

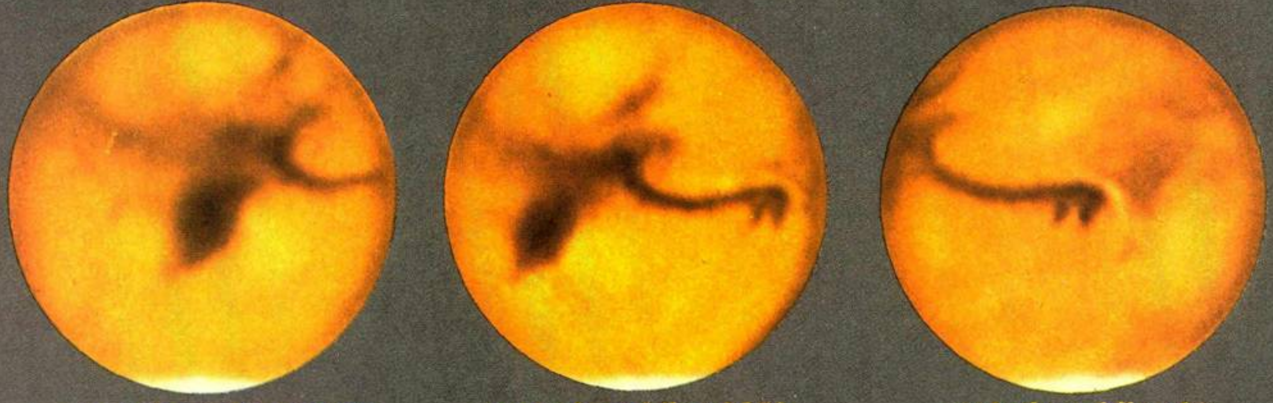

SO
180°
200°
220°
240°
260°
280°
300°
320°
340°
-60°
-50°
-40°
-30°
-20°
-10°
0°
+10°
+20°
+30°
+40°
+50°
+60°
EAST
Mare Chronium
Mare Hadriacum
Hellas
Yaonis Regio
Hellespontus
Eridania
Noachis
Hesperia
Mare Serpentis
Pandorae Fretum
Mare Tyrrhenum
Deucalionis Regio
Iapygia
Aeous
Deltoton Sinus
Sabaeus Sinus
Gomer Sinus
Tritonis Sinus
Syrtis Minor
Edom
Zephyria
Aethiopis
Moeris Lacus
Amenthes
Cerberus
Syrtis Major
Aeria
Moab
Isidis Regio
Trivium Charontis
Elysium
Phlegra
Aetheria
Neith Regio
Meroe
Eden
Propontis 1
Coloe Palus
Cebrenia
Alcyonius
Casius
Ismenius Lacus
Cydonia
Umbra
Dioscuria
Utopia
Panchaia
Cecropia
Ortygia
NO


180°
Mare Chronium
Thyle I
240°
120°
Thyle II
-70°
-80°
Argyre II
Hellas
300°
60°
Mare Australe
Argyre I
0°
SOUTH POLE

Left: the polar regions of Mars are not the easiest parts to observe. Currently, the north pole is tipped toward Earth, giving you a glimpse of the ice cap dwindling in the early martian summer. Look for a small, whitish spot. Maps by Victor Costanzo.


UTH
20°
40°
60°
80°
100°
120°
140°
160°
180°
Mare Australe
-60°
Argyre 1
-50°
-40°
Claritas
Mare Erythraeum
Mare Sirenum
-30°
Sinai
Solis Lacus
Memnonia
-20°
Coprates
Syria
Phoenicis Lacus
-10°
Aram
Margaritifer Sinus
Aurorae Sinus
Tithonius Lacus
Tharsis
Mesogaea
0°
WEST
Thymiamata
Oxia Palus
+10°
Xanthe
Ascraeus Lacus
Amazonis
Olympus
+20°
Mons
Niliacus Lacus
Nilokeras
+30°
Tempe
Arcadia
Euxinus Lacus
+40°
+50°
Mare Acidalium
+60°
Mare Boreum
Baltia
Scandia
RTH

# Mars at Opposition: 1980



February 15
8:30 p.m. EST

central meridian 290°

February 15
10:50 p.m. EST

central meridian 325°

February 16
1:15 a.m. EST

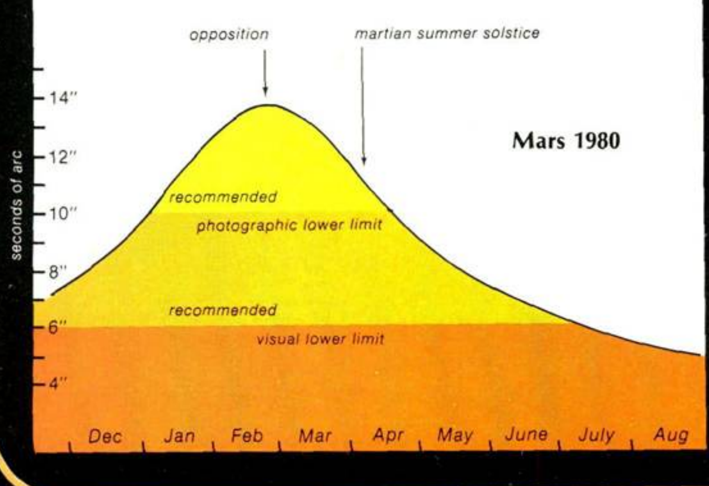
central meridian 0°

The martian day is only 37 minutes longer than ours, thus even during relatively short periods of time, new features will appear on the sunrise limb of the planet. Above are three views spread over 4¾ hours showing Meridiani Sinus as it looms into view.

Because astronomical telescopes invert an image, by agreement south is placed at the top. Thus, features at the right-hand side of the planet are experiencing sunrise, those on the left, sunset.

## Prominent Features and the Martian Disk

The table at right lists what meridian and object will be central on the disk at 10:30 p.m. EST for the dates indicated. The diagram below shows how Mars' apparent size will change over the months. The vertical scale is in seconds of arc; the horizontal one shows months. Notice how rapidly Mars swells to maximum size and then shrinks once past opposition.



| Date | Central Meridian | Major Feature |
|---|---|---|
| Jan 1 | 5° | Mare Acidalium |
| 4 | 337° | Sabaeus Sinus |
| 7 | 309° | Deltoton Sinus |
| 10 | 287° | Syrtis Major |
| 13 | 254° | Amenthes |
| 16 | 227° | Hesperia |
| 19 | 200° | Elysium |
| 22 | 173° | Amazonis |
| 25 | 146° | Mare Sirenum |
| 28 | 119° | Pheonicis Lacus |
| 31 | 92° | Solis Lacus |
| Feb 3 | 66° | Coprates |
| 6 | 39° | Mare Erythraeum |
| 9 | 13° | Oxia Palus |
| 12 | 347° | Deucalionis Regio |
| 15 | 320° | Mare Serpentis |
| 18 | 294° | Iapygia |
| 21 | 268° | Mare Tyrrhenum |
| 24 | 242° | Tritonis Sinus |
| 27 | 216° | Aeolis |
| Mar 1 | 190° | Zephyria |
| 4 | 164° | Mesogaea |
| 7 | 138° | Olympus Mons |
| 10 | 111° | Phoenicis Lacus |
| 13 | 85° | Tithonius Lacus |
| 16 | 59° | Aurorae Sinus |

you face is balancing the need for high magnification against the resulting increased distortions. Trial and error will likely be your best guide, but take a look at "Exposure in Astrophotography" and "High Resolution Astrophotography" in the August, 1978 and November 1979 issues, respectively.

Skilled astrophotographers can get good pictures of Mars with telescopes as small as 8 inches by using large f-ratios (f/100 to f/200) and high-contrast, fine grain films. Professional quality color photographs and multicolor filter black and white photographs are possible with 12-inch and larger telescopes.

### What Can I Expect to See?

The north polar cap will be the brightest feature on Mars during 1980. By January, the ice cap should be free of the cloud hood that surrounds it during the martian winter.

Around the time of opposition in late February the cap will thaw rapidly, and only a remnant will be left by the martian summer solstice in mid-April 1980. Watch for the shrinking of the cap and the associated dark "collar" which surrounds it, discovered by astronomers over 100 years ago. Also during the latter part of February keep a lookout for occasional polar clouds that will dull the ice cap. These temporary clouds occur during this part of the martian year, which is known to astronomers as the "aphelic chill."

The martian atmosphere is very dynamic. White water-vapor clouds, blue hazes in the limb regions, yellow dust, and ice fogs and frost patches from surface condensates have all been seen over the past decades. The clouds and fogs appear to be coupled with the seasonal freeze and thaw of the polar caps.

Limb hazes occur near the chilly line of nightfall, where the temperatures drop sharply. They likely are composed of fine dust particles and $CO_2$ crystals high in the martian atmosphere. You'll see them best in violet and blue light. It's still an open question how seasonal the limb hazes are.

### Mars Observing Program

The Mars section of the Association of Lunar and Planetary Observers (ALPO) runs an international Mars observing program for amateur and professional astronomers around the world. Mars observations contributed allow ALPO to sustain a program for studying the planet daily on a global basis. Anyone interested in contributing their observations and photographs to the 1980 observing program should contact the ALPO Mars Recorder, 223 W. Silver Spruce, Flagstaff, AZ 86001.

**Martian atmospheric phenomena such as hazes and clouds are best revealed by using filters. This photo was taken through a blue filter and shows hazes at both limbs. Photo by author.**

White clouds were first noted during the last century. In a spectrograph they resemble the limb hazes, but are different in that they rotate with the planet and show diurnal changes.

### Keep Alert for Changes

A remarkable W-shaped cloud that recurred each afternoon in the Tharsis-Amazonis region was discovered in 1954. Further study from Earth and spacecraft showed that these discrete clouds were created by the topography. Clouds form in summer on the up-slopes of the large volcanic peaks of Olympus Mons (138° Long., +20° Lat.), Ascraeus Mons (100°, +18°), Pavonis Mons (114°, 0°), and Arsia Mons (120°, -9°). The Syrtis-Libya basin (280°, +10°) is another area that attracts local summer clouds. But there are still many observations needed to determine how many clouds of this type exist and where they happen on the martian surface.

Certain light areas on Mars exhibit bright, white condensates at a time when the north polar cap is rapidly thawing near summer solstice. These bright patches may be either surface deposits of frost or dense ice fogs at the surface, analogous to terrestrial arctic "white-outs." Viking Orbiter photography has identified several fog-covered areas within Solis Lacus, along the Tharsis Ridge, and on the slopes of the Elysium shield volcanos. In telescopes, the bright frost and fog areas are best found with the aid of green or yellow filters.

Several light and dark albedo surface features on Mars underwent drastic changes in 1973. The Solis Lacus region (85°, -30°) bears watching as it has an observational history of changes in form and intensity. In 1973 this region showed a significant change as it had in 1878, 1911, 1926, and 1941. Solis Lacus was enlarged and skewed compared to its 1971 appearance. In June 1973, a bright streak was noted across Phaethontis-Claritas-Thaumasia. Later, an intense dark band was observed at the east end of Mare Sirenum which extended across Solis Lacus to connect with Bosporus, a distance of about 60° in longitude or 3,100 km. In 1978 a new dark feature was seen expanding in the Alcyonius-Aetheria region (260°, +38°), which was also recorded in Viking Orbiter photography. It'll be interesting to see if the appearance of these surface features is different during this year's apparition.

Mars has a perennial (really *bi-annual*) attraction which offers a lot to anyone observing it, despite its rather diminutive size. Probably the reason for this lies in its similarity to the Earth, at least when compared to the rest of the solar system. Jupiter's atmosphere may be more colorful and active, but who can feel at home with that behemoth? The remaining places in our system offer either bleak, lunar landscapes or bizarre, awe-instilling conditions far removed from human experience.

Not so with little Mars, and that's the fun of it. Here's a variegated world where you can find strange and wonderful differences — differences all the more pleasing for their closeness to terrestrial reality. The Viking mission didn't "ruin" Mars, far from it. As you look through your telescope let your mind savor the reality those craft have shown: volcanos, canyons, and vast rubbly plains. You'll miss a lot if you pass up the Mars Show this year.

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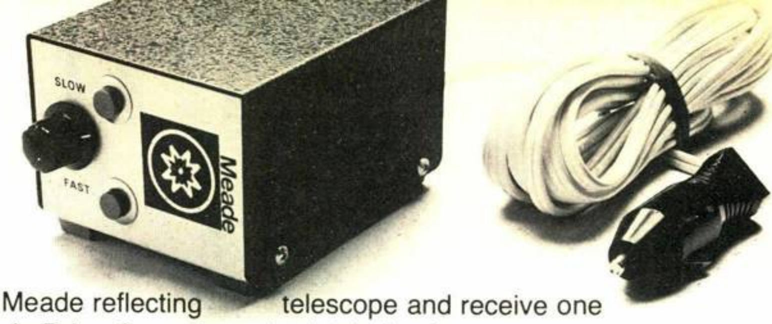

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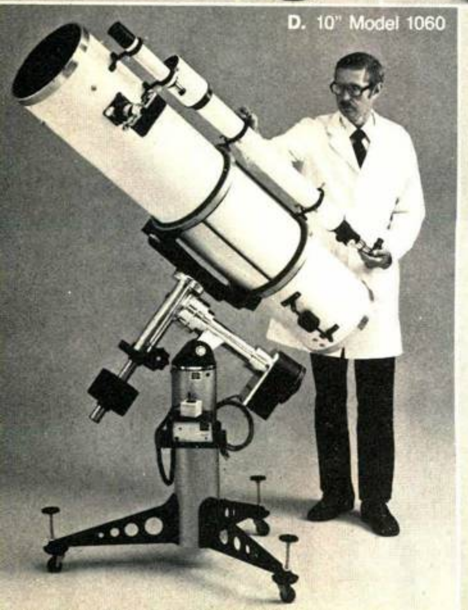
**D.** 10" Model 1060

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| | |
|---|---|
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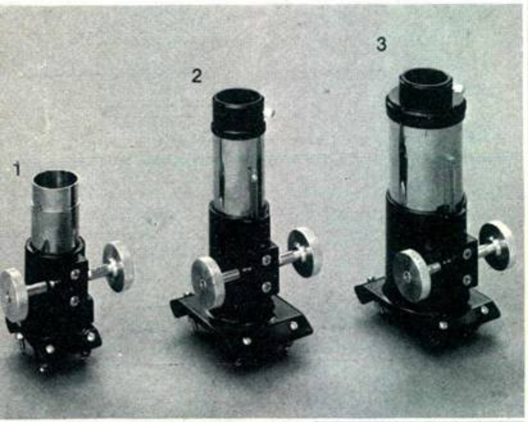

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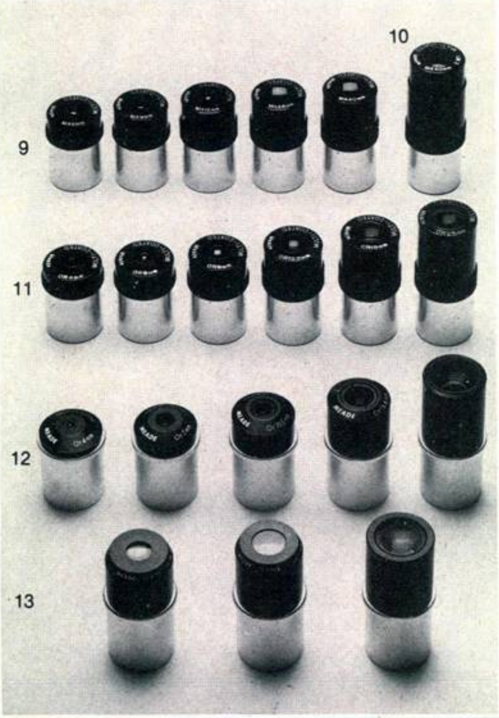

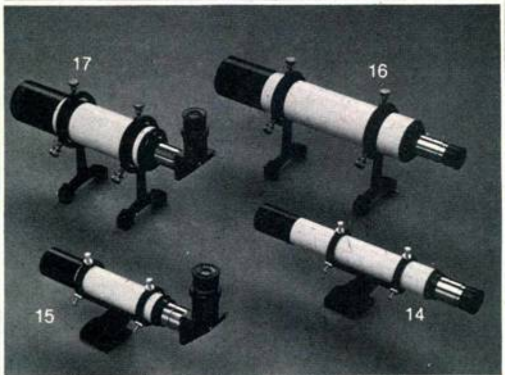

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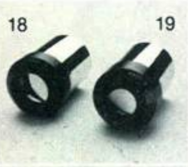

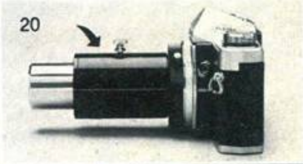

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photography
in
astronomy

# wide-field sky photography

### by David Healy

Two rival systems for deep-sky photography compete for the allegiance of those who wish to photograph larger areas of the sky than a conventional telescope allows. One system, the Schmidt camera, will capture stars 10,000 times fainter than the dimmest seen by the naked eye — in a few minutes' exposure. The other, a telephoto lens, may already be lying half-forgotten in your camera bag.

Some of the most attractive photographic targets in the heavens (the Andromeda Galaxy, the Pleiades Star Cluster, and the North America Nebula, to name a few) have angular diameters too big to fit into the 1° field of the typical telescope. Clusters of galaxies, Milky Way fields, and bright comets also overflow the image boundaries of conventional telescopes. Though these extensive subjects are a minority among deep-sky attractions, they *are* pretty and show up very well in wide-field systems.

Whether you choose a Schmidt camera or a telephoto lens may depend on your degree of dedication or perhaps fanaticism. Although in many ways they're ideal, Schmidt cameras are expensive and specialized, visually unusable, and require more than the usual amount of film-handling, as well as a special guidescope. Telephoto lenses, on the other hand, can be converted from snapshot photography into "richest field photographic refractors" by mounting them on practically any equatorially-driven telescope.

#### Just What Is a Schmidt, Anyway?

The Schmidt camera is named for its inventor, the Estonian optician Bernhard Schmidt (1879-1935). He designed the camera in 1930 to solve a very thorny optical problem found in photographic telescopes. Let's see what the problem is and how the Schmidt system gets past the difficulties.

In the typical reflecting or refracting telescope, star images and object details are sharp near the center of the field but become increasingly distorted the farther from the optical axis they are. This optical aberration is called *coma*, from the appearance it gives to point sources of light. Coma is always present no matter what the focal ratio, but becomes particularly troublesome with the lower f/numbers.

You will often see coma in photographs taken with lenses wide open at full aperture. Star images near the edge of the field look comet or blob-shaped. The effect can usually be eliminated by stopping down the lens to a higher f/ratio, but this raises other problems.

Closing down the lens opening by a "stop" cuts in half the amount of light reaching the film plane. This in turn demands a doubled exposure time. But because films lose sensitivity at the low light levels typical of deep-sky photography, an effect known as reciprocity failure sets in, which means the compensating doubled exposure in fact has to be lengthened even more. The way to avoid compounding inefficiencies is to use a fast system with a large focal area free of coma.

One way to eliminate coma is to use a spherical primary mirror. But a spherical primary introduces its own optical defect, spherical aberration, which arises because parallel light rays entering the optical system from infinity are reflected to different focal points from different parts of the mirror's radius. There's a best-focus blur rather than a sharp image.

On the other hand, if this optical system is stopped down to a focal ratio of f/5 or so by a circular diaphragm placed at the mirror's radius of curvature, the remaining spherical aberration is negligible. This design is known as the "lensless" Schmidt. Lensless Schmidts, however, have one great flaw: they're slow.

Schmidt's stroke of genius lay in replacing the lensless diaphragm stop with a much larger glass corrector plate. This thin, zero-power aspheric lens (hard to tell from a window just looking at it) is weakly convex at its center and weakly concave near its edge. Placed at the spherical primary mirror's center of curvature, the corrector lens exactly offsets spherical aberration across the entire field, allowing a virtually coma-free system with a wide photographic field. It can also be made extremely fast in the photographic sense. Its only drawback is a curved focal surface.

#### What's on the Market

Unless your budget is on the scale of the National Science Foundation, the only Schmidt cameras available today are from Celestron, which has been making them since 1971. Two models are currently offered, the 5½" aperture, f/1.65 model and the 8", f/1.5. The 5½" (20" tube, 6 lbs.) can be "piggybacked" on a Celestron 8 or other similar-sized scope. The 8-inch is larger, considerably heavier (25" tube, 13 lbs.), and requires a bigger telescope for mounting. It can also be mounted in the Celestron 8 telescope's fork mounting, in which case you'll need a separate guidescope and counterweight. Prices are comparable to those of Celestron telescopes of similar aperture.

#### Film Handling

What are the problems associated with using a Schmidt camera? The biggest headaches are all connected with film handling. Because the focal

**M-8, the Lagoon Nebula (lower), and M-20, the Trifid Nebula (upper), are two of Sagittarius' many fine attractions. Wide-field cameras work best when used for recording large star fields or extended objects. All photos by the author.**

**The Rosette Nebula in Monoceros is a 50 light-year diameter cloud of ionized hydrogen and dust charged to glow by radiation from the hot, new stars contained within it. Such objects usually show up best on a red-sensitive, b & w film such as 103a-F, used with a red filter.**

surface is curved (part of a sphere, in fact), the film has to be placed in a special holder which bends it to the correct shape.

The camera's "plates" consist of individual chips of 35 mm film clipped from a roll. You load these into the film holder of the Schmidt inside a lightproof changing bag and after exposure transfer them to a developing tank in a similar fashion.

You'll be developing the film chips yourself because few if any photo labs will handle them. Home-brewed color slides will introduce you to the overrated pleasures of the seven-solution, thirteen-step developing process. Experience has shown me that more photos are ruined by chip-handling glitches (dust, scratches, misplaced film trimmings, frames sticking together in the film tank, etc.) than by the usual blunders such as guiding lapses, kicking the telescope mount, and so on.

Ben Mayer, an experienced astrophotographer, has devised a simple way to end chip fiddling. He attached two plastic reloadable 35 mm film cassettes to the Schmidt plateholder, one acting as feeder reel, the other as take-up. You still have to load the feeder reel in the dark and advance the film between exposures in a changing bag, but these minor inconveniences mean you avoid excess handling and you can get your film processed commercially. Tell the lab to leave the film unmounted and do the job at home yourself. The extra obscuration of the film cassettes is negligible, and purists can paint them flat black.

### Is Pointing a Problem?

One other common problem that the instruction books fail to cover is how the camera, when mounted in the fork, can be pointed accurately. If you can't use it visually to determine precisely what you're aiming at, how do you align the finder scope and/or setting circles?

Easy! Slide a piece of white paper into the Schmidt's film holder and seat the holder in the camera. Turn on the telescope drive and point the camera at the Moon or a very bright star. Looking in through the open loading port of the Schmidt at the film holder, you should be able to see the Moon or star image somewhere on the white paper. Move the camera in the right ascension and declination until the image is centered. Then adjust the finder scope until the Moon or star is also centered, on the crosshairs, and it's done.

### Fields of View

Schmidt cameras have an important limitation: their fields of view are fixed. The 5½-inch instrument has a 5.9° x 8.6° field and the 8-inch a 4.5° x 6.5° field. The only adjustment you can make is to change the orientation of the film holder from horizontal to vertical.

By contrast, if you are set up for piggyback astrophotography with telephoto lenses, you can vary the field of view enormously just by switching lenses. The 50 mm "normal" lens covers a sky area of approximately 27° x 41°, while a 300 mm telephoto covers about 4.6° x 6.9°, nearly the same field as the 8-inch Schmidt.

A simple formula for approximating the sky coverage of telephoto lenses is as follows:

$$\text{field coverage in degrees} = \left(\frac{57.3}{\text{lens EFL(mm)}}\right) \times \left(\begin{array}{c}\text{film format}\\ \text{dimensions(mm)}\end{array}\right)$$

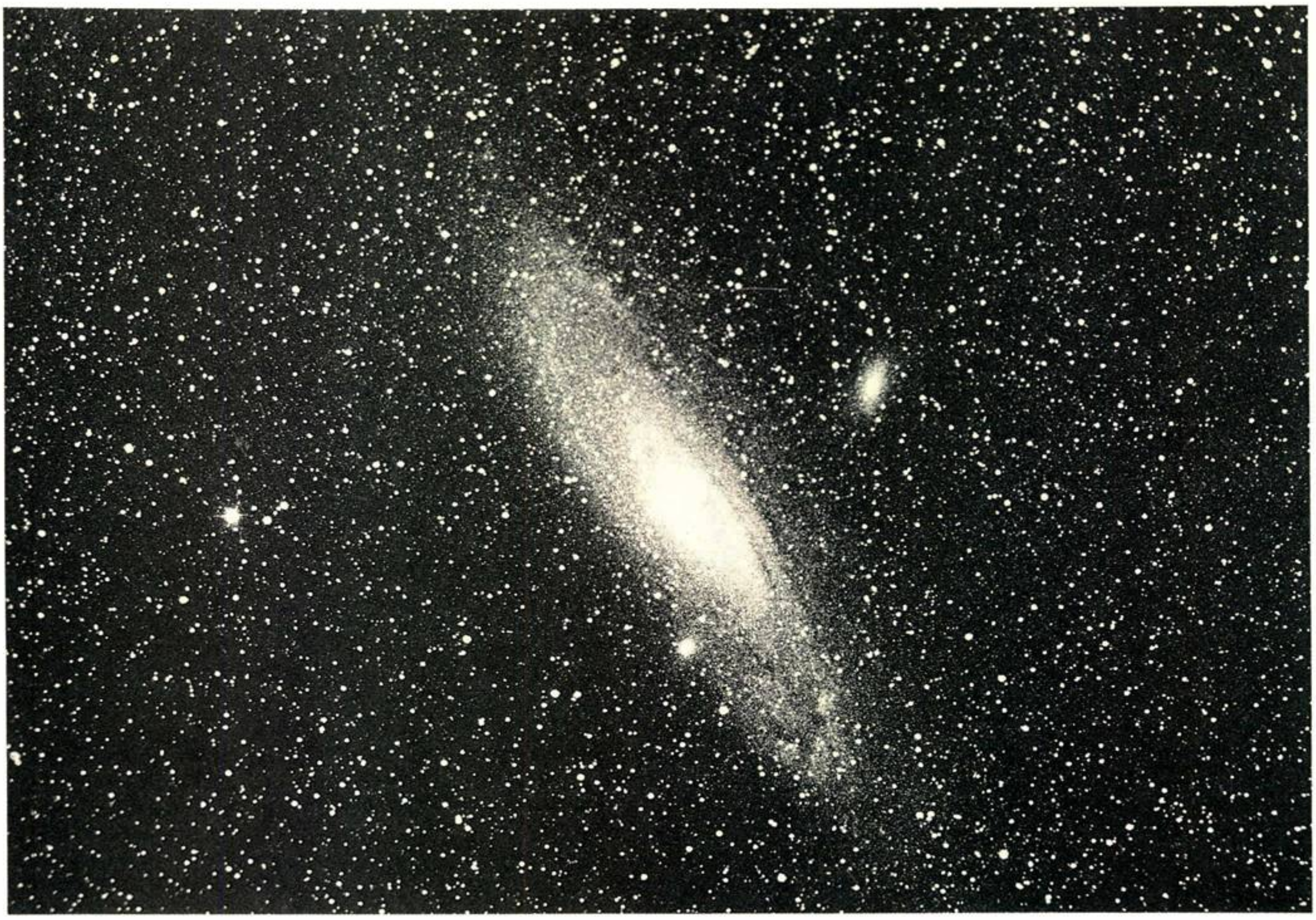
So, for example, if your telephoto lens has a 200 mm effective focal length, and the film format dimensions are those of a 35 mm camera (24 mm x 36 mm) the field coverage is 6.8° x 10.3°.

### More Pros and Cons

Another advantage of telephoto lenses is their small size and weight. A 300 mm f/4 telephoto lens attached to a 35 mm camera is about 9 inches long and weighs about 4 pounds, while the 8-inch Schmidt camera, with the same focal length and sky coverage, weighs 13 pounds and stretches over two feet long.

Of course, with the Schmidt come the advantages of system speed and resolution. The 8-inch camera's f/1.5 focal ratio means, if you neglect reciprocity failure, an exposure that takes an hour with an f/4 telephoto lens is accomplished in about 8½ minutes with the Schmidt. In practice, the Schmidt camera reaches the sky fog limit, dead overhead in a dark sky area, with exposure times ranging from about 3 minutes (for the fast, spectroscopic 103a series emulsions) to 30 minutes for some of the slower color films like Fujichrome 100. Again, neglecting reciprocity failure, the sky fog limit with an f/4 lens and Fujichrome could be more than 3½ hours.

Advertised resolutions of 1200-1300 lines per millimeter for a Schmidt camera won't be achieved in practice because even the finest grain 35 mm films you'll likely use, such as SO-115 or SO-410, have resolutions on the order of 400 lines/mm. Moreover, atmospheric turbulence and small



**The broad expanse of Andromeda's M-31 galaxy is hard to capture in a conventional telescopic picture. Telephoto lenses or Schmidt cameras with fields of view several degrees on a side are ideal for such subjects.**

guiding errors make even the theoretical limits of the film hard to achieve. Nonetheless, as telephoto/Schmidt comparison photos show, the resolution and magnitude penetration of the Schmidt is dramatically better than a telephoto lens of the same focal length and sky coverage. With the fine grain black and white film SO-115 and extreme enlargement, the Schmidt's resolution of nebular and galactic detail approaches that of a C-8 telescope.

### The Contrast Trap

One of the Schmidt's advantages, high photographic speed, can result paradoxically in a disadvantage: low-contrast photographs. A conventional telephoto lens and a black and white or color film having reciprocity failure usually supress the sky background and faint nebular and galactic detail. Bright stars and detail, however, record well and the overall result is a photo with a pleasing (actually exaggerated) degree of contrast. On the other hand, the Schmidt, having speed and high light levels at the focal surface, reduces film reciprocity failure and reproduces sky detail just as it usually occurs in nature: low contrast.

The Schmidt low-contrast originals are fairly easy to handle if the film is black and white. The 103a-series spectroscopic films are inherently high-contrast, as is their recommended developer, D-19. The combination of a #92 or #29 red filter in front of the film holder and a film such as the red-sensitive 103a-E weakens skyglow and emphasizes nebular light. "Hard" printing papers (#4 or #5 contrast grades) are indispensable in raising image contrast to agreeable levels.

Correcting the problem of low contrast color originals is somewhat more difficult. Duplicate slides, especially when done with regular Kodachrome, Ektachrome, or Fujichrome, rather than the low contrast color films made especially for slide duplicating work, will generally crank up the contrast somewhat. Duplicate slides, however, suffer from stellar image enlargement and some loss of fine detail.

### Which is Best?

Despite its problems and drawbacks, the Schmidt is a powerful tool. It is bulky, but still portable to dark-sky areas. It records stars dimmer than 16th magnitude in a few minutes' exposure. It overpowers film reciprocity failure with its low f-ratio, rendering chilled emulsions unnecessary. With fine-grain films, it can resolve detail approaching that of ordinary telescopes of equal aperture.

On the other hand, telephotos are far cheaper, more easily carried, set up quickly, require no special care in film handling, and are useful for other photographic jobs. Best of all, you may even have one already.

So which is best? Well, as always, you have to balance the trade-offs. If you're newly interested in deep-sky photos, you'd probably do best to start exploring with a telephoto or through your telescope's optical system via eyepiece projection. Remember that the wide-field subjects aren't all that many. Most deep-sky objects are small and need more magnification power than the Schmidt provides.

On the other hand, if you're really keen and dedicated to capturing wide celestial vistas, a Schmidt represents a worthy alternative. The rule of thumb here is to examine your wishes *carefully and don't rush to spend more* for a system, telephoto *or* Schmidt, than you really need.

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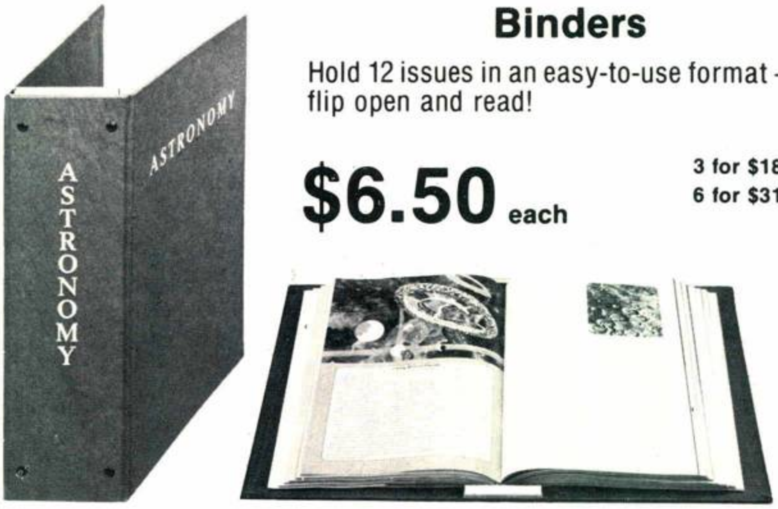

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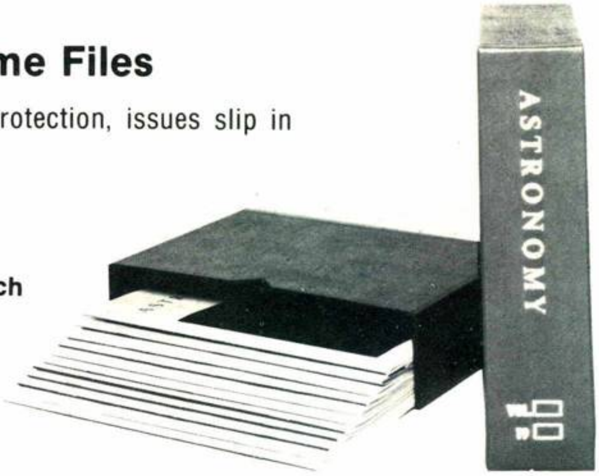

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# what good is an erfle?

Or, for that matter, what good is any eyepiece? What should it do for you? And when you're buying, what can you do to get one that does what it's supposed to? These are big questions indeed, because the eyepieces you buy can now cost a significant fraction of the cost of the telescope and will indeed have an effect on its performance. Since the eyepiece market abounds in designs, some good and some not, it's easy to get confused amid the welter of claims, counterclaims, and prices.

### A Few Eyepiece Parameters

Your telescope's eyepieces are the optical components that enable you to view the image formed by the telescope's objective mirror or lens. Most telescopes have more than one eyepiece; changing eyepieces enables you to change several important features of the telescope, namely:

- its magnification,
- its field of view, and
- its field brightness.

Simply by removing one eyepiece and plugging in another, you can change the magnification of a telescope by a factor of ten — from 60 to 600; you can change the area of sky you see from an area encompassing, for example, the disk of the full moon to dramatic close-ups showing only 1% of the Moon's visible face; and you can switch from low-power nebula hunting to splitting a close binary star system.

How do eyepieces differ to provide such a variation in telescope performance? The two major determinants of how an eyepiece will perform on your telescope are:

- its focal length, and
- its optical design.

You will see these two factors displayed in virtually every advertisement for eyepieces and you will find them etched into the cap of almost every eyepiece. Along with the brand name and a sticker saying "Passed," the eyepiece will be called a "K 9 mm" or "25 mm OR."

This cryptic notation tells you the focal length of the eyepiece (on today's eyepieces invariably given in millimeters) and the type of eyepiece (Kellner and Orthoscopic in the examples).

### Focal Length

Focal length is simply the distance to the image formed by the telescope that the eyepiece optically brings your eye. Acting like a magnifying glass, it lets you (optically) get a mere 9 mm, say, from the image at the focus of your telescope.

The closer you can get (i.e., the shorter the focal length of the eyepiece), the bigger that image will look, thus the higher the magnification the telescope gives. The longer the focal length, the less magnification the eyepiece will give, although you'll be able to see more of the image, which can be desirable. The magnification that any eyepiece will give on any telescope is:

Mag. = (Telescope f.l.)/(Eyepiece f.l.)

The normal spread of eyepiece focal lengths runs from about 32 mm down to 6 mm, though special-purpose eyepieces up to a long 75 mm and down to a short 3 mm are made. Eyepieces in the normal range usually turn out to be the ones you want.

Intimately connected to the focal length of the eyepiece is a parameter controlling the brightness of the images seen in your telescope: the *exit pupil*. The eyepiece lenses form an image of the telescope's objective (the *entrance pupil*) just outside the eyepiece. That image is the exit pupil. All the light that enters the telescope leaves through the exit pupil; in fact, when you look through a telescope, you are putting your eye right into the exit pupil.

The size of the exit pupil determines how bright the image will appear. If the pupil is big, the image is bright, but not magnified much; if it's small, the image will be relatively dim, but highly magnified. You can find the size of the exit pupil as follows:

Exit pupil = Telescope aperture /Mag.

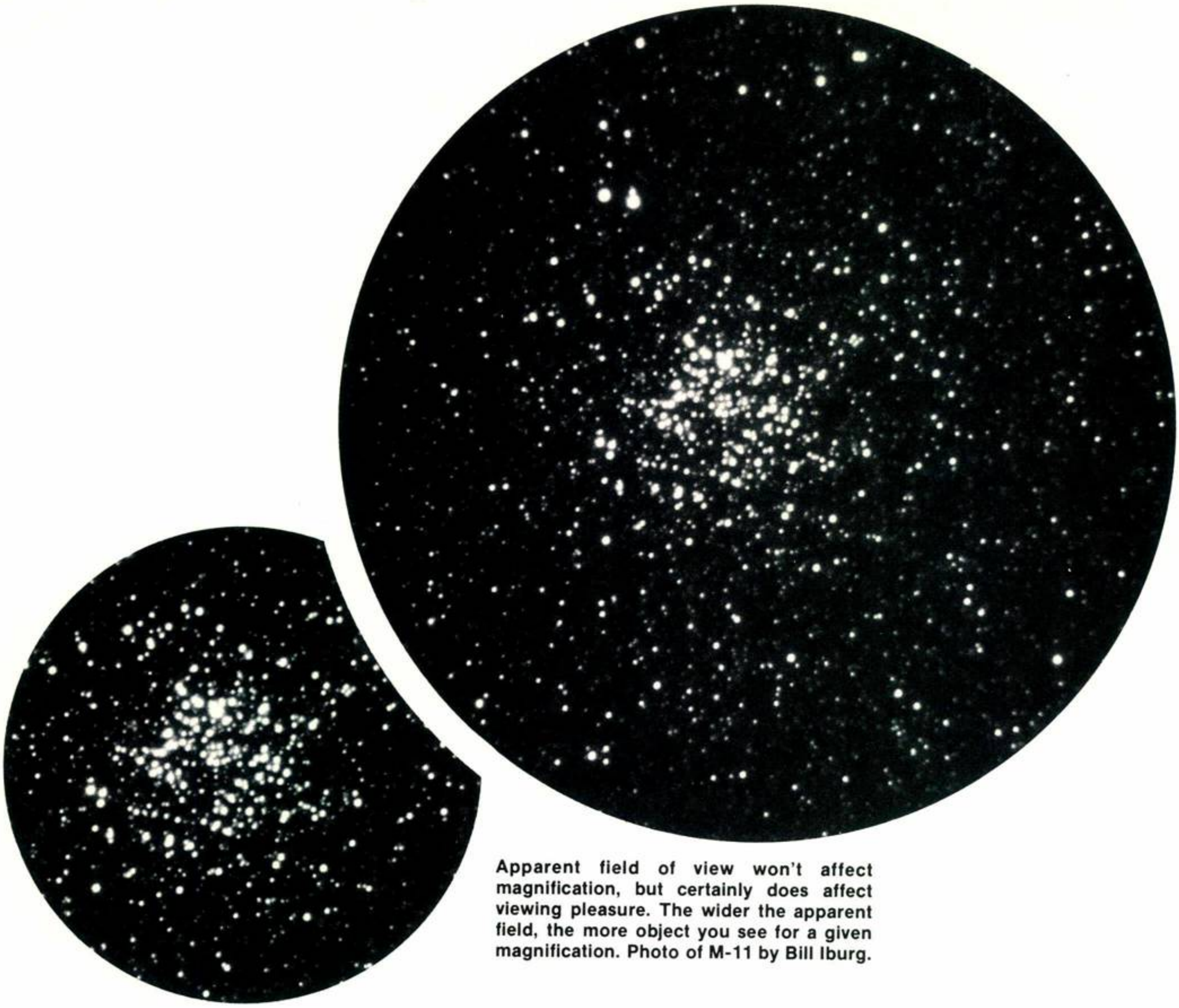
When choosing a set of eyepieces, the size of the exit pupil provides the very best guideline to follow. Your goal in using an eyepiece is to transfer light from the telescope efficiently into your eye. No light should be wasted, and for best results, you'd like to match the telescope's resolution capabilities to the resolution of your eye.

For all the light from the telescope to enter your eye, the exit pupil cannot exceed 7 mm. This "lowest power" is called the *normal magnification*. In choosing a set of eyepieces, select at least one that will give you an exit pupil between 5 and 7 mm.

Your eye forms its very sharpest image when the beam of light entering it is about 2 mm in diameter — approximately the diameter of your eye's pupil under optimum daytime lighting conditions. If you want an "ideal" eyepiece, get one that will give a 2 mm exit pupil. This will almost perfectly match the resolving power of your eye to the resolving power of the telescope. The image viewed at this power will be very satisfyingly sharp.

Experienced observers say that they can see the most planetary detail with an exit pupil of about 1 mm — about twice the magnification of the "ideal" resolving power match. The image will look slightly fuzzy, but you'll see more. If you want to see the festoons of Jupiter's belts and the markings of Mars, obtain an eyepiece giving this exit pupil.

Finally, if you want to split close



**Apparent field of view won't affect magnification, but certainly does affect viewing pleasure. The wider the apparent field, the more object you see for a given magnification. Photo of M-11 by Bill Iburg.**

double stars and push your telescope to the limits of its abilities, buy yourself an eyepiece which will give an exit pupil of 0.5 mm size. The magnification provided by such an eyepiece will be the highest you'll ever find use for.

### Eyepiece Type

All eyepieces are not the same: a wide variety of different optical designs are commercially available today. You will find advertisements for these in ASTRONOMY and in manufacturers' catalogs. The eyepiece design, or type of eyepiece, controls three important parameters:

- apparent field of view,
- eye relief, and
- aberration correction.

The apparent field of view is the angle occupied by an image in the eyepiece. When you place your eye properly in the exit pupil, the apparent field of view is the angle of the diverging cone of light formed by the exiting light rays from one edge of the field and light rays from the opposite edge.

The apparent field of view is an important part of the pleasure of looking through a telescope. The larger it is, the better illusion you'll get of actually being out there in space. An apparent field of view 60° in diameter is usually enough to be pretty impressive. If it's less than 30°, it can seem claustrophobic — like looking through the microscopes in high school biology lab.

For a given magnification, the larger the field of view, the more sky area you can see. This makes it easier to find deep-sky objects, for example. To a first approximation, the following equation is true:

Real f.o.v. = Apparent f.o.v./Mag.

When you look through a telescope having a magnification of 60x with an eyepiece having an apparent field of view of 60°, you're able to see a 1° real field of view.

Eye relief, or the distance between the eyepiece lens and the exit pupil, is determined by the eyepiece type also. It is important because if there is inadequate eye relief, you can't comfortably squeeze your eye close enough to the eyepiece to see the entire field.

Observers who wear glasses are often at a loss because many eyepieces, especially those with short focal lengths, don't provide adequate eye relief. These observers must remove their glasses at the telescope.

On the other hand, observers who don't wear glasses may find the eye relief of some low-power eyepieces too great. Rather than being able to rest their eye comfortably against the rim of the eyepiece, it's necessary for them to hold their head back from the eyepiece, which is difficult to do for any length of time. Proper eye relief is, to some extent, a matter of circumstance, taste, and observing experience.

Finally, eyepieces may introduce errors, or *aberrations*, into the image of the telescope. These may be color errors because the eyepiece has simple rather than achromatic lenses in it, or they may be field errors in which the eyepiece lenses can't sharply focus light near the edges of the field of view.

Aberration correction depends on the optical design of the eyepiece — how the lenses in the eyepiece are arranged. In general, the simplest and least expensive eyepiece designs have the worst aberrations. More complex types give the sharpest images across the entire field, usually have the widest fields, and are carefully designed to give proper eye relief.

### Huygenian Eyepieces

Huygenian eyepieces have been around for several centuries — in fact ever since Christiaan Huygens invented them in the 1600s. They consist of two simple (i.e., nonachromatic) plano-convex lenses mounted with the curved side of both lenses facing the telescope objective. They are supplied only with the cheapest equipment, usually in subdiameter (0.917") size and they aren't very good. The field of view is usually about 30°, eye relief is terrible, and with modern fast Newtonians they can't provide a truly sharp image even at the center of the field. With small refractors (which are usually about f/15) they can provide acceptable definition.

### Ramsden Eyepieces

Ramsdens eyepieces are a big step up from Huygenian eyepieces, even though they too consist of two simple plano-convex lenses. The differences are that the spacing between the lenses is altered and the two convex sides face each other. This underscores how important eyepiece design is in influencing performance.

Ramsdens are quite inexpensive, so if you're on a really tight budget, you could buy Ramsden eyepieces for your high-power viewing. Ramsdens cover a 30° field of view and have some color fringing near the edges of the field, but provide acceptable central performance for telescopes with f-ratios of f/8 or higher. The eye relief is about three times greater than a Huygens and about two-thirds as good as the fanciest designs discussed in this article.

### Kellner Eyepieces

Kellner eyepieces are very common: they're the design you'll find on most binoculars and other "consumer optics." Kellners cover a 40° field of view and have considerably better color correction than Ramsdens, but the eye relief is not as good. You'll find that most Kellner eyepieces sold for use with astronomical telescopes are of relatively low power (18 mm to 40 mm focal lengths), which means the short eye relief is not much hindrance in their use. If you're somewhat short for money, buy a low-power Kellner to complement your higher-power Ramsdens.

### Orthoscopic Eyepieces

Orthoscopic eyepieces give a 40° field of view and excellent eye relief. Color aberrations at the edge of the field are well corrected and orthoscopics give a flatter field (the field is in sharp focus all over) than Kellners do.

Orthoscopics are made in a very wide range of focal lengths, from the short 4 mm high magnification jobs up to about 25 mm in focal length. They are a good choice for examining planetary and lunar details at high power, and satisfactory at lower magnifications as a general-purpose eyepiece.

### Erfle Eyepieces

OK, what good is an Erfle? Erfles provide a full 60° field (and some of the more exotic variants provide up to 70°) as well as having excellent eye relief. They give you the feeling you could walk right into the image.

Erfles became popular after World War II put millions on the surplus optics market. Some of them are still around, but the newly manufactured ones are better, having optical coatings on the lenses to reduce internally reflected light, and being made of clearer modern optical glass. (Many of the surplus Erfles are yellow or brown.) A good Erfle won't give you quite as sharp an image at the center of the field as a good orthoscopic will, but they're sharper out near the edge of their much larger field than an orthoscopic.

Erfles are best for low-power viewing and so they're made in the 16 mm to 40 mm focal length range. Because of their wide fields of view, some Erfles are mounted in 2-inch-diameter barrels since the standard 1¼" barrel would not allow their full field to be used.

### Plossl Eyepieces

Plossl eyepieces are extremely sharp over a moderately wide 40° field of view. They have excellent eye relief (better than an orthoscopic's), and give somewhat nicer images than an orthoscopic, especially when used with short f-ratio reflectors. Color fringing is minimal even at the edges of the field.

Plossls are sold in a wide range of focal lengths, although their best use lies in the middle to high-power range where superb image sharpness is more important than a wide field.

### Other Types

There are many other named eyepiece types: Bertele, Konig, Symmetric, Achromatic Ramsden, R.K.E. — the list could go on and on. Most of these are improvements or extensions of the basic Ramsden, Kellner, Orthoscopic, or Erfle designs — and they perform as well or better.

### Making a Choice

Choosing an eyepiece or a whole set of eyepieces is not an easy job. You don't have much to go on unless you attend a lot of star parties and look through lots of telescopes and ask "What kind of eyepiece do you have in it now?" and "Can I try out that Erfle of yours in my telescope?" Of course, that's not a bad idea.

Eyepieces seem suspicious — as if they all come from some little factory in Japan which is willing to engrave any retailer's name on the outer rim. Maybe there even *is* some truth to that — but you'll never know. Most eyepieces on the amateur telescope market today seem to be well made and really are the honest-to-goodness design the label says they are. Look around at lots of eyepieces if you can, and when you buy, buy from a reputable dealer. If you keep them clean when you try them out, and don't get lint or fingerprints on the lenses and dust on the insides, you can return an eyepiece that's not adequate to the dealer.

When building up a set of eyepieces, pick and choose among the types for your different observing functions. Start by figuring out what focal lengths will give the optimum exit pupil for wide-field, best-field, and planetary observing with your telescope. Figure out what magnifications those eyepieces will give — then look at that list and see if there are logical gaps in it. You may want a magnification midway between wide-field and sharp-field, or perhaps one very high power for double star splitting. Then sit down to read ads and catalogs. Choose those types and focal lengths that will give you what you want.

You've got a lot of choices. If low cost is very important, buy a low-power Kellner and a planetary Ramsden. Later add a second Ramsden for medium power. You'll get good value from them. For the best wide-field observing, get an Erfle plus a set of orthoscopics or Plossls for the higher magnifications. You may prefer a nicely matched set of "parfocalized" eyepieces, which means that when you remove one and slide another into the focuser tube, it'll be in focus without turning the focus knob. It's certainly handy. Or, if you're a deep-sky nut, you might want to convert your telescope over to the 2-inch focuser size to accommodate a big wide-field eyepiece for great deep-sky observing.

Whatever eyepieces you choose, if you treat them carefully and keep them clean, they'll last you a long time.

— *Richard Berry*

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# AstroNews

## Solar Maximum Prompts Intense Study of Sun

About 400 scientists from the United States and 17 foreign countries are combining their resources to get the maximum benefit from studies of the Sun as it nears a time when sunspots, flares, and other activity will reach a climax early in 1980.

The National Science Foundation (NSF) has named Dr. David M. Rust, a solar physicist, to head the office of science coordinator. The office will be located at the Goddard Space Flight Center in Greenbelt, Maryland and will be supported by NSF and the National Aeronautics and Space Administration.

Termed the Solar Maximum Year (SMY), the effort actually will last 19 months — it started August 1 and will last until February 28, 1981. About 15 U.S. universities will participate. The NSF plans to increase its support of solar research during the SMY.

Sunspots, solar flares, and other turbulent activity on the Sun vary in number and intensity with a cycle which peaks once every 11 years on the average. The greatest activity on the Sun in recent years was in September 1957. In that solar maximum year, the number of sunspots — using the Zurich method of counting — was 201, the highest ever recorded. (The Zurich method is one of several ways of counting, depending on such variables as which telescope is used and who is doing the observing.)

"The upcoming sunspot maximum," Dr. Rust said, "is expected to be the second largest since regular sunspot counts began in the seventeenth century when Galileo made the first telescopic observations of sunspots."

The SMY's coordinated effort should help scientists understand how solar flares build up, how tremendous amounts of energy are released from the flares, and what the effect of solar activity is on the space between the Sun and the planets.

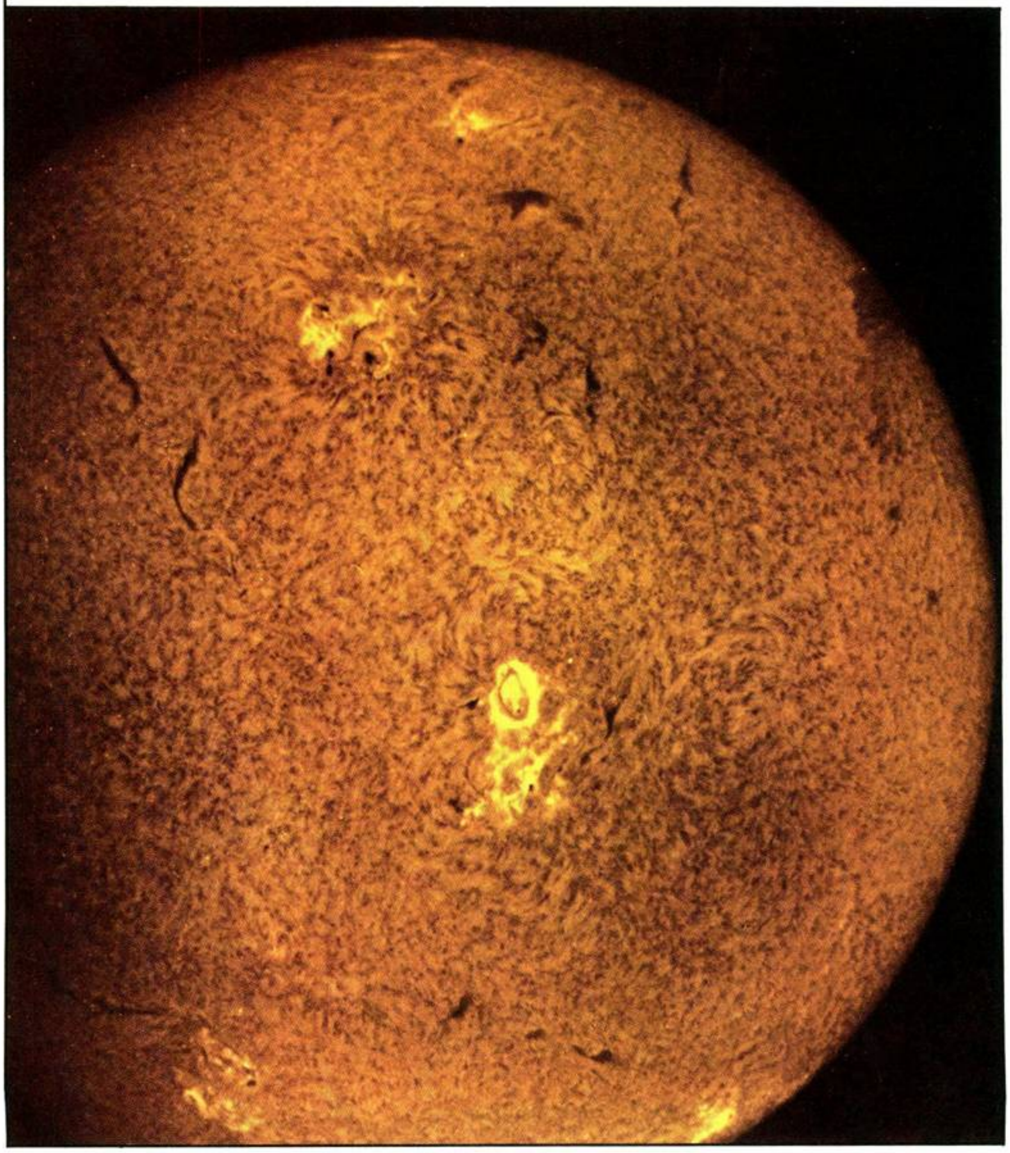
Flares are violent disturbances on the Sun's surface which are accompanied by the ejection of giant streams of energetic subatomic particles. Large flares can adversely affect radio communications and X-rays emitted by the flares may interfere with television reception.

"Until our understanding of solar flares is greatly improved," Dr. Rust said, "there will be no sound basis for predicting when solar activity will affect the terrestrial environment. Besides disturbing communications, solar flare emissions heat up the Earth's upper atmosphere and, perhaps, trigger changes in the weather."

Recent discoveries suggest that the solar cycle is not the dependable periodic phenomenon that most astronomers had assumed it to be. Several times in recorded history, solar activity apparently all but disappeared, with serious consequences for living conditions on Earth. (See "A New Revolution in Solar Physics," ASTRONOMY, February 1979.) The last disappearance of solar activity coincided with the coldest part of the Little Ice Age from about 1645 to 1715.

A number of national centers will participate in the SMY, including: Sacramento Peak Observatory in Sunspot, New Mexico; Kitt Peak National Observatory near

*A large flare is clearly visible in this hydrogen alpha photograph of the Sun taken on September 11, 1979, by Edwin Hirsch. Such flares are expected to be common during the current solar maximum.*



Tucson, Arizona; the National Radio Astronomy Observatory in Greenbank, West Virginia; and the High Altitude Observatory of the National Center for Atmospheric Research in Boulder, Colorado.

Earth-based observations will be supplemented by a number of space missions, including the planned NASA Solar Maximum Mission scheduled for launch this month and the already operative International Sun-Earth Explorers, which have been returning valuable data for several months already. These current and planned missions will provide many important observations in parts of the electromagnetic spectrum not observable from beneath Earth's atmosphere, and in regions of interplanetary space between Earth and the Sun.

Scientists hope that the intensive and coordinated effort of the Solar Maximum Year will result in tremendous advances in our understanding of the Sun's structure and dynamics.

## Jupiter Mission Postponed

Dr. Thomas A. Mutch, associate administrator of NASA, announced to a House of Representatives subcommittee that delays in the development of the Space Shuttle have caused NASA to postpone the planned Galileo mission to the jovian system until 1984 (see AstroNews, December 1979).

The original plan was to have a single Shuttle launch one spacecraft to Jupiter in 1982. This craft would have carried both the Jupiter orbiter and an atmospheric probe designed to descend into the mysterious clouds of the solar system's largest planet. Instead, they now plan to launch the two components of the Jupiter mission separately in 1984, from two different Shuttle flights.

According to Dr. Mutch, NASA decided such a revised plan was "the most cost-effective and least-risk approach to retain the Galileo scientific objectives." However, the change in plans is expected to add more than $184 million to the cost of the mission, originally estimated at about $450 million. Therefore the proposed revision must be approved by both the President and Congress.

## Anti-Cosmic Rays

Antimatter has the same characteristics as matter except the electrons and protons that make up antimatter have charges opposite to matter, and are known as positrons and antiprotons. (Antineutrons, which like neutrons have no electric charge, are distinguished in another manner.) When the two forms of matter encounter one another, the result is mutual annihilation — a total transformation into energy. Many cosmological theories predict that the universe should be composed of about equal amounts of matter and antimatter, but scientists have had difficulty explaining how the two antagonistic forms of matter could be held separate from each other. There is no way to tell by observations alone whether a particular celestial body is composed of matter or antimatter, so the question has remained open.

Now researchers at New Mexico State University (NMSU) have announced the first detection of antimatter in cosmic rays, which implies that at least some antimatter exists in our own Milky Way Galaxy.

Small numbers of antiprotons were observed during an eight-hour balloon flight at 120,000 feet with the aid of a 5000-pound instrument. Dr. Robert Golden of NMSU led the team which recorded data on over one million cosmic rays which passed through the equipment.

The balloon, launched from Palestine, Texas, carried a powerful superconducting magnet and radiation sensors to measure the cosmic ray masses, energies, and charges. When the data were analyzed, a total of 46 antiprotons were observed, or roughly five antiprotons to every 10,000 normal (positive) cosmic ray protons. Details of the discovery were reported in the October 15 issue of *Physical Review Letters*.

The antiprotons were not left over from the origin of the universe, but instead were made by nuclear reactions within the Galaxy during the last 10-30 million years, Golden explained. Cosmic rays are believed to result from stellar explosions and are highly energetic. As they speed through interstellar space, they occasionally collide with the nuclei of hydrogen atoms in interstellar gas clouds, resulting in equal amounts of matter and antimatter.

Such collisions have been simulated in Earth laboratories, but cosmic rays themselves never reach Earth's surface because of the thick shroud of Earth's atmosphere. Instead, a "rain" of secondary particles is produced by the original single particle of the cosmic ray. Therefore the high altitude experiment was necessary to detect the cosmic rays before they interacted with the atmosphere. Theoretical calculations indicated that there should be about 4.4 antiprotons for every 10,000 protons as a result of collisions taking place in interstellar clouds. The proportion observed in the experiment was almost exactly that predicted.

The immediate significance of the discovery of naturally occurring antiprotons is that it demonstrates that antimatter, contrary to the theories of some scientists, is quite stable and not subject to decay into ordinary matter. According to Dr. Golden, "The real question is, if we understand particle physics so well and the theories predict the universe was made of equal amounts of matter and antimatter, what happened to the antimatter from the creation of the universe?"

Of course, physics may have been different at the time the universe was created. Because of the physicist's belief that "laws don't change," this is a "profound realization," said astrophysicist Golden. "At tremendous energies, something may be different."

The questions raised about the creation of the universe will be studied by elementary particle scientists, Golden said. What he plans to do in the months ahead is refine the current process of observing what happens in the violent stellar explosions which give rise to cosmic rays. His experiment also demonstrated that present detection methods are reliable and accurate enough to observe even minute traces of antimatter, according to Golden. He will make improvements on his equipment before the next balloon flight, scheduled for September 1980. He also plans to conduct experiments on the Space Shuttle, which has an advantage over balloons because in outer space all atmospheric interference is eliminated.

## Cannibal Galaxies

We know that galaxies are the fundamental constituents of the universe, and although they are found grouped together in clusters, the incidence of close double or multiple galaxies is relatively rare. For this reason most astronomers think galaxies evolve individually in splendid isolation.

But the discovery of a galaxy which has apparently swallowed up another galaxy has cast doubt on this model of single galactic births. F. Schweizer of the Cerro Tololo Inter-American Observatory announced at a meeting of the Astronomical Society of the Pacific that he and his colleagues have found that

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the galaxy NGC-1316, identified as the radio source Fornax A, contains within itself a rotating cloud of hydrogen gas so massive — 100 million suns — that it must also be a galaxy. NGC-1316 does not rotate as a whole.

The astronomers conclude from this that NGC-1316, already known to be disturbed in form, has actually devoured what was once a close companion galaxy. If such cannabalism is widespread, Schweizer points out, there should be a large number of such disturbed galaxies. And in fact there are quite a few of these galaxies, many of which don't have companions which (by tidal interactions) could account for their distortions.

Since statistically it is unlikely that these cannibal galaxies were the result of random galactic collisions, Schweizer concludes that far more galaxies formed originally as double or multiple systems than has been thought. Orbital decay of these systems would fairly soon bring about a merger of the original constituents into strange galaxies like NGC-1316.

## Pseudo-Science Update

Two areas of pseudo-science, widely accepted by the lay public, have come under scientific attack recently. A respected Belgian astronomer has challenged the prediction that an alignment of the planets in 1982 will have disastrous consequences for the Earth, and a prominent science writer has attacked the notion of "UFOlogy" as a science.

Writing in the July-August 1979 issue of *Mercury*, the journal of the Astronomical Society of the Pacific, Dr. Jean Meeus has shown that a close alignment of the planets will not occur in 1982, and that even if it did, its effects on the Earth would be negligible.

The prediction comes from a popular book, *The Jupiter Effect* (written in 1974 by John Gribbin and Stephen Plagemann), which forecasts that a rare alignment of the planets would cause activity on the surface of the Sun to flare up considerably. This in turn would mean that more solar particles would reach the Earth, slowing our planet's rotation just enough to trigger major earthquakes (see Star Dome, ASTRONOMY, August 1979).

Dr. Meeus points out that there will simply not be a real alignment of the planets in 1982. While the planets will be on the same side of the Sun that year, they will never be less than 95° apart — more than one-quarter of a full circle. If we consider only the largest planets in the solar system, it still turns out that they will never be less than 60° apart in 1982.

But even if the planets were perfectly aligned, Dr. Meeus contends that there is simply no evidence that the Earth would be affected. Going back to historical records, Dr. Meeus showed that at previous times when the planets were even closer to each other than they will be in 1982, there was no significant increase in solar activity. On January 16, 1901, for example, the largest planets were only 25° apart, yet solar activity was at a minimum.

Furthermore, the Belgian astronomer has also found that several centuries of earthquake observations show no correlation between the amount of solar activity and the number of earthquakes.

Thus the prediction of major earthquakes in 1982 as a result of the alignment of the planets cannot be taken seriously at this time, Dr. Meeus concludes.

Another popular pseudo-scientific topic, UFOlogy, has also been recently subjected to a scathing critical analysis. A widely publicized UFO Essay Competition sponsored by the British magazine *New Scientist* and Cutty Sark Ltd. (London) has been won by a man who does not "believe" in UFOs. The prize, which included an award of £1000, went to James Oberg, a well-known UFO skeptic and critic who is a fellow of the Committee for the Scientific Investigation of Claims of the Paranormal. Oberg, a space specialist at NASA's Mission Control in Houston, is also the UFO columnist for the new popular science magazine *Omni* and a frequent contributor to ASTRONOMY.

The competition was announced in mid-1978 with a series of prizes being offered, including one million pounds sterling for an authenticated piece of a UFO (there were no claimants for this prize). The scientific paper competition attracted more than 200 entries, which were judged anonymously by a panel consisting of Dr. Bernard Dixon (former editor of *New Scientist*), Dr. Patrick Moore (astronomer and author), and the late Dr. Christopher Evans (psychologist).

The title of the winning paper is "The Failure of the 'Science' of UFOlogy." In his paper Oberg lists what he sees as serious shortcomings in UFO research to date. While not denying the possibility of anomalous stimuli behind a tiny fraction of UFO reports, Oberg does not see any proof for such a hypothesis. Without better scientific standards, he contends, the study of UFO reports will continue to fail to prove anything — or to disprove anything. The full text of the paper was published in the October 11 (1979) issue of *New Scientist*.

The Committee for the Scientific Investigation of Claims of the Paranormal (CSICOP) was formed by a group of scientists and science authors in response to what was believed to be a dangerous growth in public acceptance of, and even belief in, a number of pseudo-scientific theories and phenomena. In addition to Oberg, CSICOP numbers among its fellows the well-known science writers Isaac Asimov, Martin Gardner, and Dennis Rawlins, astronomers George Abell, Bart J. Bok, and Carl Sagan, and psychologist B.F. Skinner.

An annotated bibliography covering scientific views of UFOs, astrology, ancient astronauts, the Bermuda Triangle, Uri Geller, and other areas of pseudo-science has been made available by the Astronomical Society of the Pacific. Part of a series of resource materials produced by the A.S.P., the listing is designed to provide teachers, students, and the public with reliable references for investigating these controversial fields. Copies of the list can be obtained by sending 35 cents to:

Pseudo-Science List
A.S.P.
1290 24th Avenue
San Francisco, CA 94122.

## Light Pollution Studied

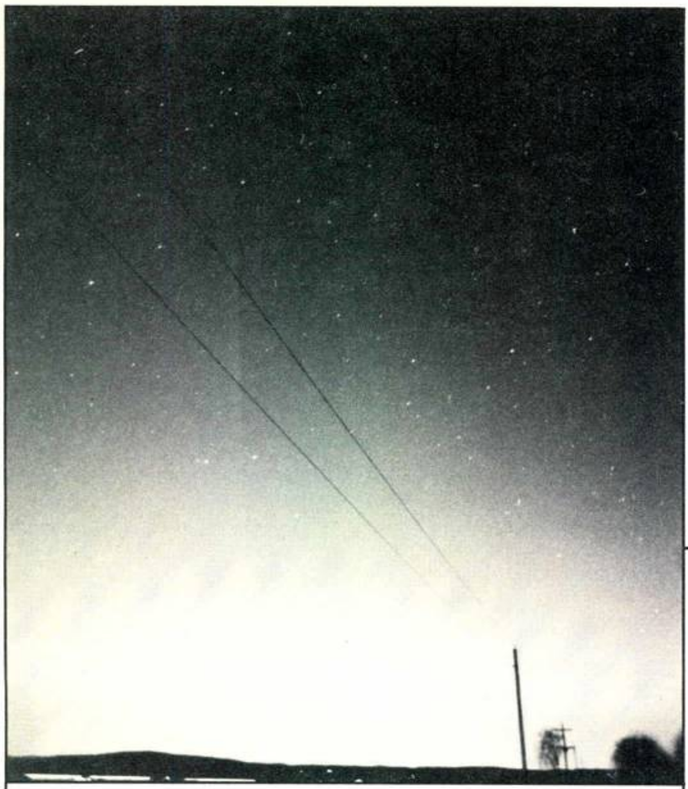
Add the light bulb to the list of sources of pollutants afflicting modern society. And add to the list of species endangered by pollution the astronomer who often is effectively blinded by the glare of outdoor lighting that washes the stars from the night sky, a phenomenon tagged *light pollution*.

Astronomers have watched with increasing concern the growing use of outdoor lighting, which is projected to triple in the next 10 years. Studies of the phenomenon so far have been restricted to isolated sites, but an associate professor of astronomy at Wesleyan University, Arthur Upgren, is organizing one of the first systematic studies of light pollution on a large scale. Scheduled to begin next summer, his research project may provide data that have social as well as scientific implications.

With assistance from the research support group called EARTHWATCH, Dr. Upgren plans to train about 50 volunteers next summer to build and use portable light-measuring instruments. After their five-day training session at Wesleyan, the volunteers will return to their home towns throughout the United States and begin taking measurements, which they will forward to him for analysis.

EARTHWATCH is a private, nonprofit group, with headquarters in Belmont, Massachusetts, that recruits volunteers to participate in scientific research projects throughout the world. Upgren's project is one of 60 expeditions they will sponsor next year in 17 states and 25 foreign countries. The group's volunteers are of all ages and are drawn from all walks of life. EARTHWATCH will supply up to $14,400 for the training of Upgren's volunteers, who will report to Wesleyan in four teams next July and August. Some of the volunteers will receive full or partial scholarships from EARTHWATCH to cover the cost of their participation.

The device the volunteers will use for measuring extraneous light is called a



*The glow of lights has rendered modern cities unsuitable for astronomy. The above photo was taken looking south over the city of Toronto. Photo by Richard Berry.*

visual photometer, which they will construct from a design by Richard Berry (Editor of ASTRONOMY magazine) published in the February 1978 issue of *Sky & Telescope*. The photometer enables the user to determine the brightness of the background illumination from the sky by matching it with a fixed source of illumination provided by a small battery-operated bulb.

Dr. Upgren will consider various factors in analyzing the volunteers' raw data, including population of the community, the distance from the city's center at which measurements are made, time of night, and atmospheric conditions. He believes data obtained over a period of time will enable him to gauge the growth of outdoor lighting accurately, and plans to correlate the light pollution data with the 1980 census figures to determine whether night illumination can be used as a tool to estimate the population of an area.

Upgren says outdoor lighting, especially that used by municipalities, is the fastest growing component among all uses of electricity. While overall energy consumption increased by 25% during the last decade, the use of electricity for outdoor lighting went up by 300% during the same period, twelve times faster.

"We have to be careful not to substantiate an argument in advance of collection of the data. It might turn out that there no longer is an increase, but preliminary evidence indicates that outdoor lighting continues to increase steadily," he observed.

Dr. Upgren wants to establish a network of volunteers to make observations during all seasons of the year by enlisting the aid of amateur astronomers in the project.

"It's my feeling that not enough attention is paid to amateur astronomers by professional astronomers. They're quite sophisticated in some areas and are able to make substantial contributions," said Upgren, who has addressed several groups of amateur astronomers in New England on the topic of light pollution.

Upgren believes one problem encountered in combating light pollution is that it is not taken seriously by the general public. "Light pollution is not yet widely perceived as a problem but only as an inconvenience to stargazers. It appears to be just one more social cause taking its minor place amid the rising clamor of partisans of other social causes."

Dr. Upgren is interested in light pollution not only because it interferes with his professional work and teaching but also because of its broad social implications. He fears that if outdoor lighting continues its unchecked growth, its demands for electricity could be a major cause of increased reliance upon nuclear power in the near future.

Moreover, he's worried that night lighting is being installed for the wrong reasons. Upgren claims that municipalities are eager to erect more and more lights because city officials think lights will reduce crimes.

"There is no evidence that outdoor lighting deters crime, including assault and rape, according to evaluation programs sponsored by the U.S. Department of Justice and others," he said. "Successful crime-deterrent measures may go unfunded if unsuccessful ones like street lighting are allowed to persist."

(Anyone interested in helping with the monitoring work should write to: Dr. Arthur Upgren, Dept. of Astronomy, Wesleyan University, Middletown, CT 06457.)

# A Fading Sun?

In demonstrating the existence of sunspots, Galileo destroyed the concept of the Sun as a perfect sphere without flaw or blemish. Nevertheless, belief in the Sun as an exceptionally stable and unchanging body (at least for billions of years, both past and future) has long been accepted as almost an astronomical article of faith. But recent research has raised serious questions about the absolute stability of the Sun, the ultimate source and support of all life on Earth.

It is both sobering and humbling to realize how little is actually known about the structure and dynamics of the Sun, the nearest star to Earth. Despite all the modern sophisticated equipment and

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# AstroNews

devices which have been employed in recent years, a great many mysteries and uncertainties remain to puzzle scientists. One of the greatest of these in recent years has been the so-called "mystery of the missing neutrinos." The commonly accepted theory of the Sun's internal power source involves very specific thermonuclear reactions, and according to this theory, there should be a certain number of neutrinos (detected as a "neutrino flux") emitted from the Sun's core. Neutrinos, capable of passing through light-years of solid lead without interacting with matter, flow straight out through the overlying layers of the Sun into space.

Despite their intrinsic independence, a tiny minority of the enormous number of neutrinos passing through a suitably large detector will in fact react with the detecting material. It is this fact which underlies the design and construction of the world's strangest telescope. It is strange enough to say that scientists have built a telescope to observe the interior of the Sun — and that is exactly what Ramond Davis' neutrino detector is designed to do — but it sounds nothing less than occult to report that this "telescope" actually consists of a tank of 100,000 gallons of cleaning fluid buried deep under Earth's surface in a gold mine in North Dakota. The neutrinos interact with chlorine atoms in the cleaning fluid and produce a radioactive form of argon gas which can easily be detected in small quantities. The tank must be buried to shield it from other sources of radiation to insure that the chlorine-argon transformation is due only to neutrino reactions.

The problem is that after ten years of observation, the number of neutrinos that have been detected is only one-third the predicted number. In attempting to deal with this discrepancy, astrophysicists have proposed a number of solutions, most of which, unfortunately, have been rather far-fetched. Some of the less exotic models have included very strong magnetic fields, a rapidly rotating solar core, and a lower-than-expected amount of heavier elements at the Sun's center.

According to the model which calls for a low abundance of heavy elements, such a lack at the Sun's center would make the interior more transparent to radiation, which means that lower core temperatures suffice to produce the observed luminosity at the surface. Lower core temperatures imply a slower rate of thermonuclear reaction, and hence the production of fewer neutrinos. The problem with this model is that the abundance of heavy elements actually observed on the Sun's surface turns out to be about 10 to 20 times higher than that necessary for the required internal transparency.

Of course there is no reason why the abundance of heavy elements observed at the surface of the Sun should be the same as that in its center, and this simple observation is the basis of a recent theory proposed by J. Christensen-Dalsgaard, Douglas Gough, and Guy Morgan of the University of Cambridge (England) and published in *Astronomy and Astrophysics* (volume 73). They argue that the observed abundances are due to the Sun's having been "contaminated" by interstellar dirt and dust since its formation and are not representative of internal conditions. This "dirty Sun" theory adequately accounts for all the observed properties of the Sun (including the low neutrino flux), but that the Sun could have remained in this undifferentiated state for billions of years is somewhat doubtful.

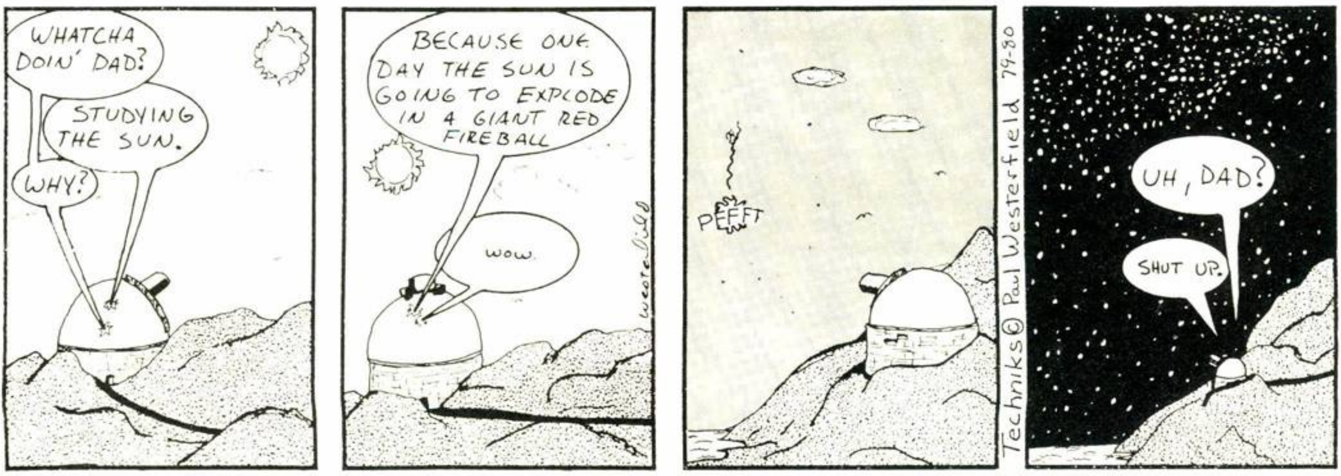
There is a way of checking the model, however. If the Sun oscillates, the period of the oscillations would be very sensitive to the internal abundance of heavy elements. This is because the period depends on the speed of sound within the Sun's internal layers, which in turn is affected by the temperature and heavy element abundance of the various layers.

In fact, the Sun may indeed oscillate. New observations published in the February 22, 1979 issue of *Nature* by P.H. Scherrer and J.M. Wilcox of Stanford University and by A.B. Severny, V.A. Kotov, and T.T. Tsap of the Crimean Astrophysical Observatory tend to confirm earlier observations of a 160-minute pulsation of the Sun. If real, these pulsations involve a change in the Sun's diameter of about 10 kilometers (6 miles) — a tiny oscillation indeed, considering the Sun's average diameter of 860,000 miles. Yet such oscillations would be sufficient to produce profound effects, including a greater rate of internal mixing and a higher rate of energy flow from the center to the surface. While the higher mixing rate would raise problems for the "dirty Sun" hypothesis, which assumes an especially rigid internal layering, it isn't yet possible to evaluate the significance of short-term solar oscillations for the missing neutrino problem since an enormous number of interrelated factors are involved.

If the Sun actually does pulse every two hours forty minutes, astrophysicists have before them the monumental task of reconstructing the theory of solar structure and dynamics practically from scratch, and no one now knows what such a reworked theory would predict.

But the Sun may be even more variable than this. In fact, it may have been shrinking for the past several centuries, according to a report presented to the American Astronomical Society last June by John A. Eddy of the Harvard-Smithsonian Center for Astrophysics and Aram A. Boornazian, a computer specialist at S. Ross and Co. in Boston. Eddy is well known for his historical studies of past solar behavior and in many ways has been a modern Galileo, an apostle of solar variability attacking the "sacred" tenet that the Sun is constant and unchanging.

According to Eddy and Boornazian, annual averages of the Sun's horizontal (east-west) and vertical (north-south) diameters over the years from 1836 to 1953 show a decline amounting to about two seconds of arc horizontally and one second vertically. Such a fast shrinkage couldn't be sustained for a very long time, so it is thought that this is a temporary phenomenon,


WHATCHA DOIN' DAD?
STUDYING THE SUN.
WHY?
BECAUSE ONE DAY THE SUN IS GOING TO EXPLODE IN A GIANT RED FIREBALL
WOW.
westerfield
PFFFT
Techniks © Paul Westerfield 79-80
UH, DAD?
SHUT UP.

perhaps preceded by an expansion. Therefore the shrinkage, if real, could be part of a long-period solar oscillation.

If the Sun is indeed shrinking, this could explain the mystery of the missing neutrinos. It may be that the thermonuclear reactions at the Sun's core have temporarily "cooled down" and the shrinkage is an adjustment to that. Such an adjustment should affect the total energy output of the Sun, measured by what is called the "solar constant."

In a paper published in the June 22, 1979 issue of *Science*, Sabatino Sofia, John O'Keefe, and Janet Lesh of the Goddard Space Flight Center and Andrew S. Endal of Louisiana State University concluded from their study of past records that the solar constant has not changed by more than one-third of a percent over the time from 1850 to 1937. Their data also indicate a much smaller rate of solar contraction — one-fifth that found by Eddy and Boornazian. It is clear that more study is needed to determine whether or not the Sun is in fact shrinking and if so, to what extent — and to what extent this would cause a decline in the solar constant.

A variable Sun would have tremendous impact on Earth, because even a small change in the solar constant would result in significant climatic changes on Earth. The dearth of sunspot activity during the late 1600s has been linked to the "Little Ice Age" in the northern hemisphere, but no plausible mechanism for the link has been worked out. A recent paper, however, by Robert H. Dicke of Princeton University, published in *Nature* (July 5, 1979), suggests that both solar activity (as measured by such effects as sunspots, faculae, prominences, flares, and the solar wind) and solar luminosity (which would affect our climate) are caused by changes in a magnetic field deep within the Sun.

Dicke refers to a study of climatic variability made by Dr. Samuel Epstein and Dr. Crayton Yapp of Caltech, which was based on the relative abundance of deuterium and hydrogen in cellulose extracted from the annual rings of two bristle cone pine trees over a period of 1000 years. The ratios indicate the average temperatures during each year—the less the deuterium relative to hydrogen, the warmer the weather, and *vice versa*. In analyzing their results, Dicke noted that the irregularities of the sunspot cycles, varying from eight to seventeen years, were absent, but instead a regular period of 22 years appeared clearly. He reasoned that this variation was due to an intrinsic variation in solar luminosity over this period.

It is already known that the Sun's magnetic polarity reverses in a 22-year cycle, twice that of the sunspot period. Dicke points out that the Epstein-Yapp data indicating a regular climatic variability show a clear 22-year period, and his theory suggests that both the sunspot cycle and the temperature variation resulting from a variation in solar luminosity are due to a deep internal magnetic "clock." This model would solve the problem of how the sunspot cycle could influence Earth's weather by ascribing both phenomena to a third, as yet undetected cause deep within the Sun.

According to Dicke's theory, the next period of maximum earth temperature is due to coincide with the sunspot maximum early in 1980. But if, as Eddy and Boornazian suggest, the Sun is shrinking, we may be in for a long, cold winter.

# Spinning Life

As scientists continue their investigations of other planets, trying to understand how Earth's atmosphere was formed, and speculate whether or not a supernova ended the reign of the dinosaurs, evidence has come to light linking still another kind of large-scale astronomical event to Earth's climatic conditions and consequently to terrestrial life. Exposing another facet of the growing concept of an extraterrestrial ecosystem, Australian meteorologist B.G. Hunt recently announced his findings that the tidal forces generated by the Sun and Moon could have been instrumental in the successful evolution of higher life on our planet.

Writing in the British scientific journal *Nature*, Dr. Hunt points out that Earth's spin is one of the most important influences on weather and that Earth now rotates 2 to 2½ times slower than during the late Precambrian era, 1.5 billion years ago. The results of his computer studies at the Australian Meteorological Research Center indicate that the stronger wind-turning effect of the Precambrian Earth's spin (called the Coriolis force) would have given the younger planet a dramatically different climate. According to Dr. Hunt, a "high rotation rate in a fluid system reduces the characteristic size of dynamic features, their associated transport processes, and the overall intensity of the motions."

Simple computer models designed to simulate the effect of a high rate of rotation on the climate of Precambrian Earth reveal that such a high rate may have been inimical to the evolution of multicellular organisms. While conditions near the equator would have been similar to the present, higher latitudes would have been considerably drier and colder. "The general aridity and/or coldness at higher latitudes suggest a rather harsh climate unattractive to all but the hardiest life forms at that time." But as Earth's rotation gradually slowed over the ages, these higher latitudes "would have become progressively habitable," according to Dr. Hunt.

Limited precipitation, one of several climatic effects caused by the rapid spin, would have made water scarce on land and rivers would have delivered far less material to the seas and flood plains. Wind stress on Earth's surface may have averaged only half that of today. According to Dr. Hunt, the single most important effect would have been the reduced rate at which winds enriched ocean waters by circulating nutrients between various depths.

Because of the harsh side effects of rapid rotation, terrestrial organisms may have had to wait until the tidal effects of the Sun and the Moon slowed the Earth sufficiently to produce a more benign environment in which evolutionary development could take place. The inexorable tug of tidal forces may have "imposed an important, and possibly dominant, effect on the genesis and termination of the Precambrian ice age," Dr. Hunt says. By the end of the Precambrian era, about 600 million years ago, the slowing of Earth's spin over the millennia had lengthened the day from nine hours to about twenty. The ice sheets covering the higher latitudes then began to recede as a result of increased atmospheric circulation from the equatorial zone.

If Dr. Hunt's admittedly speculative analysis is correct, it may provide an explanation for the failure of single-celled organisms, forms which appeared over 2.5 billion years ago, to evolve into higher forms until the end of the Precambrian era, when a flurry of diversification began. If this were the case, the apparently accidental presence of our large natural satellite, the Moon, may be indirectly responsible for the relatively rapid appearance of higher forms of life and even man himself. Without the Moon, many more millions of years would have been required for the Sun alone to slow Earth's rotation enough to create a suitable environment for large land forms.

Other scientists have even speculated that the Moon is responsible for the emergence of life from the oceans onto dry land. Without a massive moon and its consequent tides, according to this theory, life would not have been subject to a fluctuating land/sea interface and therefore would not have evolved forms capable of surviving on dry land, or at most would have done so only very slowly. Even though we now bask in the climate created by the present rate of rotation, the story is far from over. Our day length is still increasing at a rate of about 2.5 thousandths of a second per century and eventually will equal a month — but a month of 47 days, for by that time the Moon will have receded to a greater distance than at present and will revolve around the Earth once in 47 days. At that time in the distant future, Earth will be rotationally halted with respect to the Moon whose cratered surface will appear to hang motionless in the sky when viewed from Earth's near side. But long before that time, both Earth and the Moon will have been destroyed by the Sun's evolution into a red giant star. In the meantime, though, we may look forward to further climatic changes as a result of Earth-Moon interaction. Dr. Hunt's findings urge scientists to consider the importance of rotation not only in understanding the climate of Earth's past but also its present and future.

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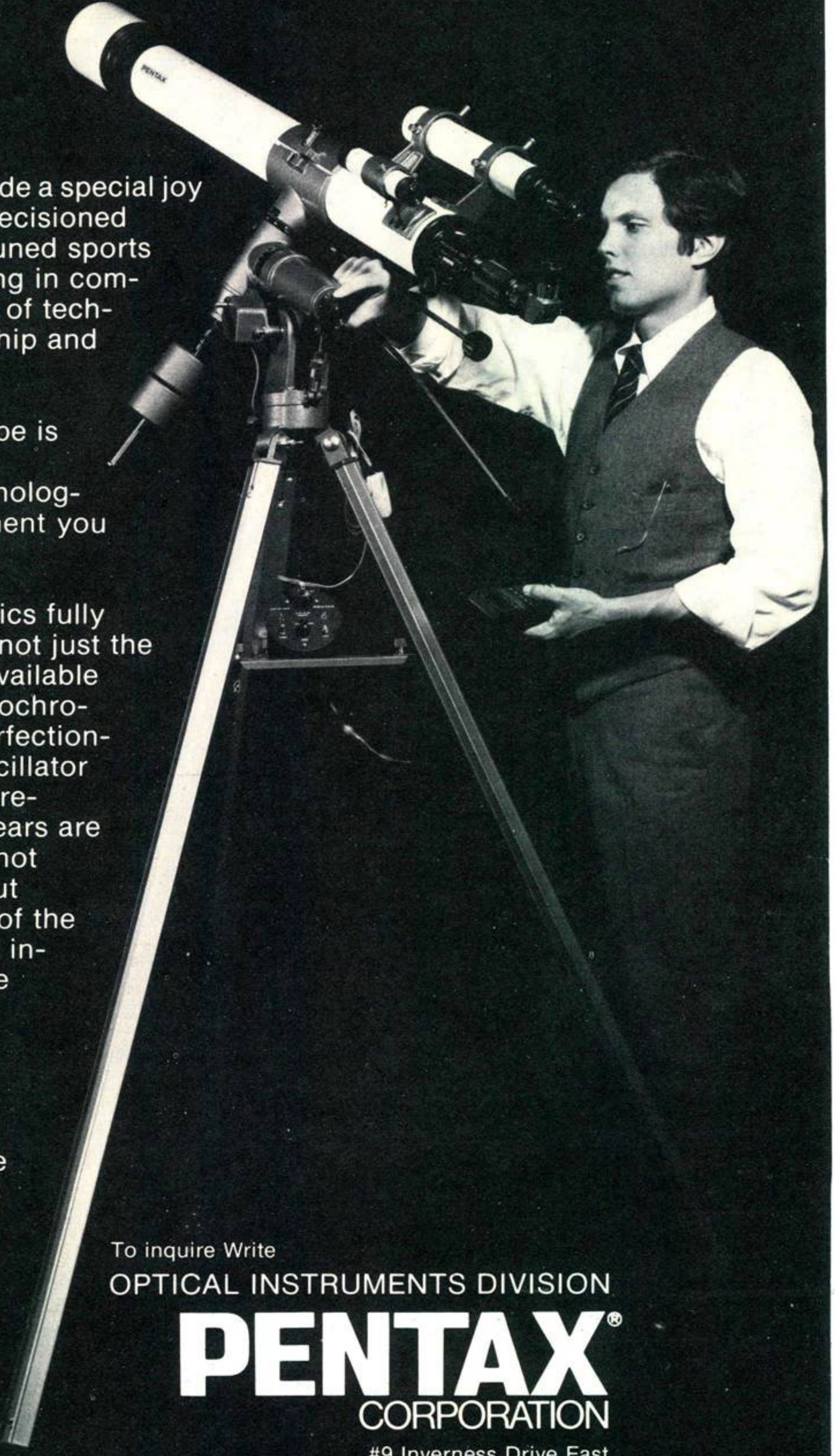

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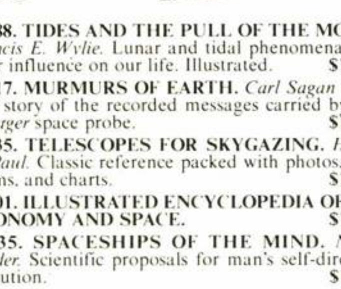
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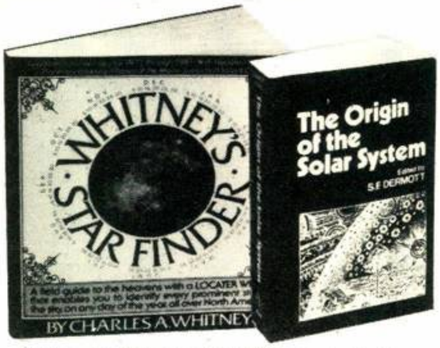
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# Was Einstein Wrong?

## by James S. Trefil

General relativity is a little like democracy. Almost everyone believes it's a good thing, but few can justify that belief. Since Albert Einstein published his theory in 1915, it has never been subjected to the kind of intensive experimental scrutiny that other laws of physics have undergone, including Einstein's earlier (1905) Theory of Special Relativity, which has been confirmed to a high degree of accuracy and is now one of the fundamental cornerstones of modern physics. But general relativity, despite the beauty and elegance of its equations, doesn't rest on such firm experimental ground as special relativity. For that reason, other scientists have advanced a number of competing theories in recent years.

Just what evidence is there for general relativity? Textbooks speak of three classic tests: the *bending of light*, the *gravitational redshift*, and the *perihelion advance of Mercury*. We'll discuss these in detail later, but in fact only the first two of these are actually crucial tests of the theory and only one of them (the bending of light) is highly supportive of the theory at the present time. The problem is that the unique effects peculiar to general relativity, even on a scale as large as the solar system, are so small that truly heroic efforts are required to detect them. This has meant that throughout most of the lifetime of the theory, tests of its accuracy have produced only very poorly determined values. Why this has been so, and why this is changing now, is the story of this article.

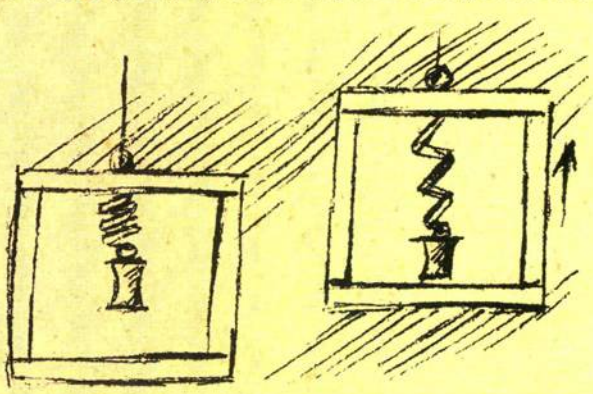
### What is General Relativity?

General relativity is really a theory about the force of gravity. This is a familiar force — it keeps us firmly attached to the Earth, causes apples to fall, and holds the Earth in orbit around the Sun. But in 1915 it was very poorly understood. Einstein's achievement was to show that the general features of gravity could be understood in terms of a single universal principle: the Principle of General Relativity. Furthermore, he showed that a specific theory incorporating this principle could describe the details of the way the force operates. This theory — the theory of general relativity — is the basis for our modern claim of understanding the phenomenon of gravitation.

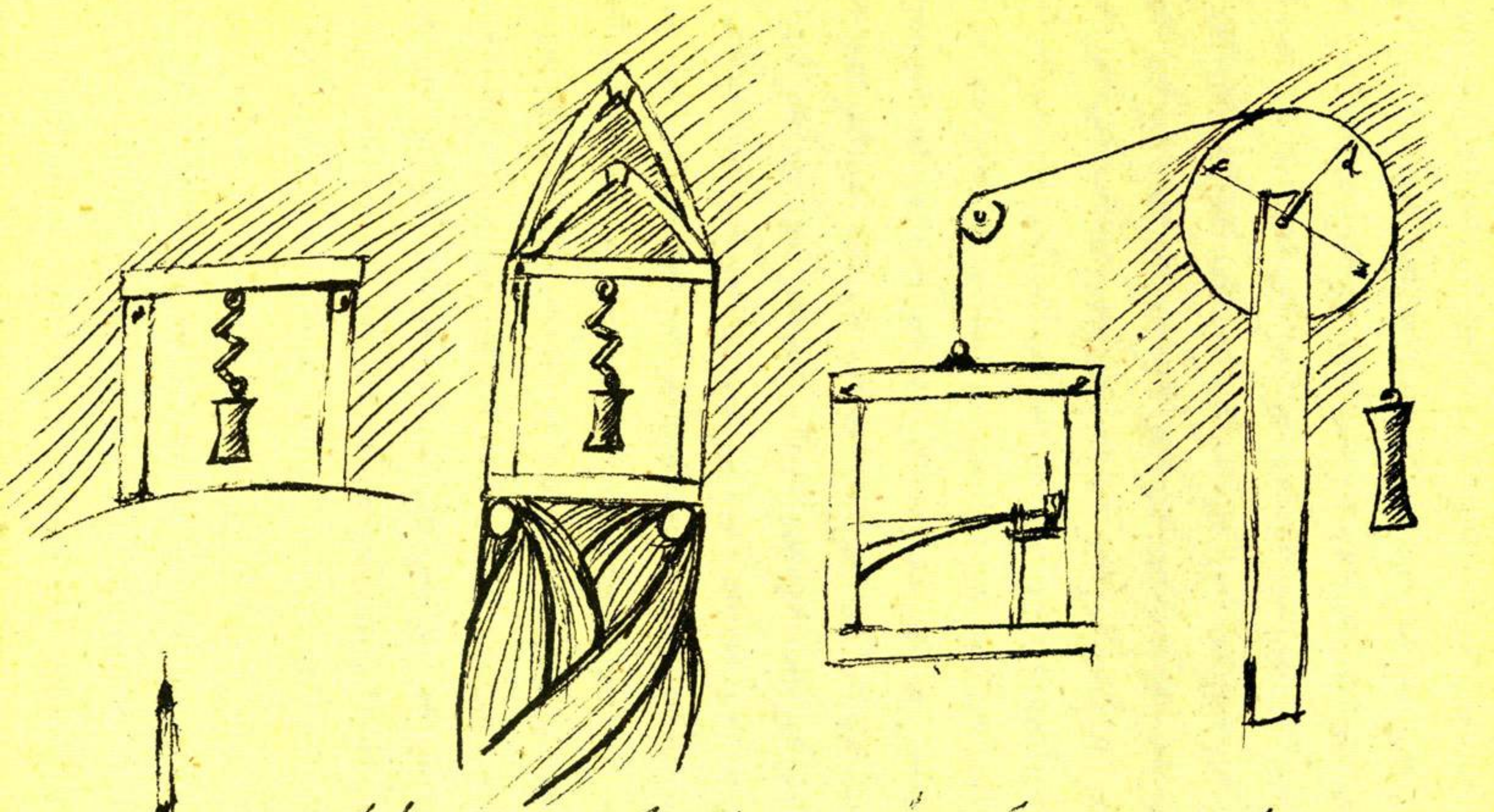
The distinction between the principle and the theory is important for our discussion. There are many theories of gravitation on the books right now, and general relativity is only one (the one, however, that most scientists think is right). Every one of these theories, though, incorporates the Principle of General Relativity, so all of our modern thought about gravity can be said to be founded on Einstein's ideas even if some modern theorists differ from Einstein in the way they think the details should be worked out.

The principle is deceptively simple. It just says that the laws of nature should appear to be the same to everyone in the universe. Period. Like most revolutionary statements, it looks simple and almost self-evident. And like most revolutionary statements, when its consequences are completely worked out, they are far-reaching indeed.

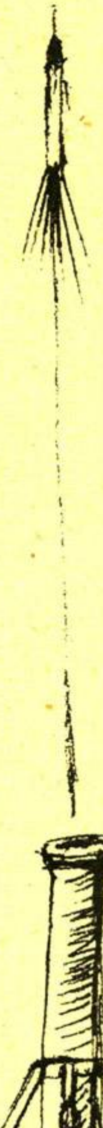
Let's see how this principle can lead to some rather startling predictions about the world. We can start with an experience we've all had. When you are in an elevator that's just starting up, particularly if it's a modern elevator in a tall building, there is a moment when you feel as if you're being pressed into the floor — almost as if you are momentarily heavier. In the same way, when the elevator starts down, you feel a transitory sensation of "floating" — of being lighter. If you were standing on an ordinary bathroom scale while you were in the elevator, the scale would actually record a greater weight than normal on the way up and a lesser weight on the way down. If we were pressed for an explanation of why this should be so, we'd probably say that on the way up the floor is pushing the scale up against our feet, causing it to read a higher weight, and on the way down the scale was falling away from our feet, causing us to press more lightly on it. But in both cases, we would have to say that the motion of the elevator had an effect similar to the force of gravity by influencing the reading on the scale.

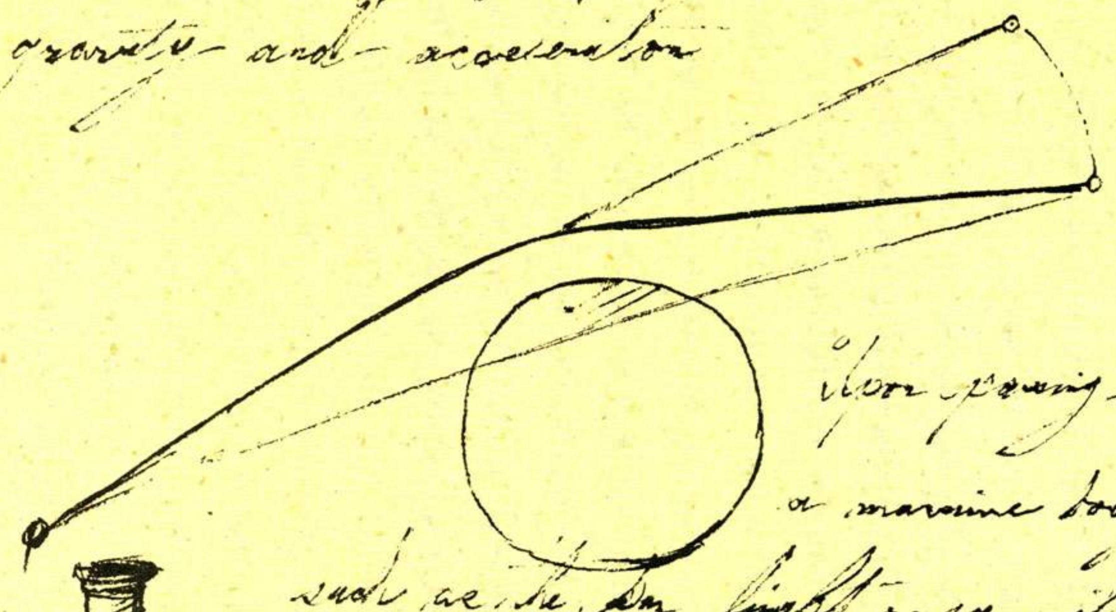


To see the relevance of this everyday example to the principle of general relativity, imagine taking this elevator out into deep space somewhere where we are far away from anything that could cause a gravitational force. If we now started pulling the elevator up, a person standing on a scale inside would feel himself pressed down against the floor and would see the scale recording some weight. If we adjusted the upward acceleration of the elevator to be just right, the scale could be made to show a "weight" identical to what the person would see if he were on the surface of the Earth. In fact, there is no way that person could tell he

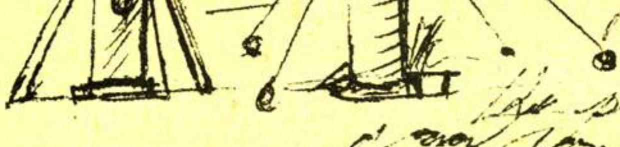


The principle of general relativity produces the essential equivalence of gravity and acceleration





Upon passing a massive body such as the sun, light rays will be bent from their original path. General Relativity also predicts a loss of energy on the part of light ascending a gravitational field.



wasn't on Earth, experiencing normal gravity. To him, the effects of acceleration and the effects of gravity would be indistinguishable. This, in essence, is the meaning of the principle of relativity. It tells us that the laws of nature (and, in particular, the law of gravity) have to appear to be the same to someone standing on Earth and to someone being accelerated. As a result, the force of gravity is indistinguishable from the force caused by an acceleration of our frame of reference.

Let's look at another experiment the man in the elevator could do. Suppose, mindful of historical precedents, he dropped an apple. If we watched this from outside, we would say that the accelerating floor of the elevator would come up and hit the apple. The man in the elevator, however, doesn't think he's accelerating. As far as he's concerned, the apple leaves his hand and winds up on the floor — in other words, it falls. Again, he would see the same thing as someone standing on the surface of the Earth. And again we see a connection between what we call gravity and simply observing events from an accelerating frame of reference.

A final experiment: Suppose the man in the elevator marks two spots six feet "up" on the wall. Now suppose, while the elevator is accelerating upward, he shoots a beam of light from the first mark, directed toward the spot on the opposite wall. Watching from the outside, we could see the opposite wall move upward while the light is crossing the room, and this would cause the light to hit below the mark.

The man in the elevator, watching the same set of events, would see the light start out from a "height," of six feet and hit the opposite wall below that height. Since he thinks he's in an area where gravity is operating, he would conclude that light must be affected by gravity, and that light beams will "fall" under gravity's influence. From this he would conclude that light passing near a massive body like the Earth, the Moon, or the Sun would be drawn in toward it, just as a satellite would be. Thus, light rays near the Sun should be bent.

### The Bending of Light Rays

Most of us are probably aware that it was the verification of this prediction of the bending of light rays that catapulted general relativity into international prominence and made Einstein a household name. What is not as well known is the fact that every theory of gravitation will predict light bending, and what distinguishes general relativity from the rest is the amount of bending predicted.

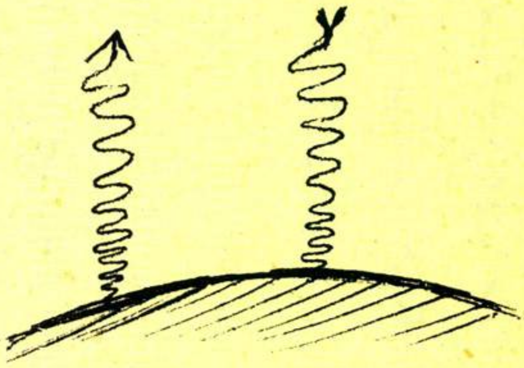
To see how this phenomenon arises, let's think about what happens when we look at a star whose light must go near the edge of the Sun before it gets to us. As the light gets near the Sun, it starts to "fall" inward. This means that when it gets to Earth someone who sights along the light beam will think that the star is actually located to one side of its true position. The apparent shift of the star's position is due to the bending of the light.

Measuring the deflection of light should be easy, then. All we have to do is take a photograph when the star is near the Sun, being sure to include some reference stars whose light doesn't go near the Sun, and then compare it to a photograph of the same set of stars six months later, when they are in the night sky and far away from the Sun.

The only problem with this scheme is that under normal circumstances, light from the Sun will blot out starlight, making any pictures impossible. So in order to check the prediction about light bending, we have to take our photographs when the Sun is totally eclipsed. And this, in turn, makes the measurement very difficult, because eclipses seem to have a habit of occurring in places rather inhospitable to astronomy, like deserts, tundras, and inaccessible mountain ranges.

In 1919, Arthur (later Sir Arthur) Eddington took a group to the island of Sobral, off the east coast of Africa, to photograph the region around the Sun during totality. When the photographs were compared with those taken 6 months before, stars near the edge of the Sun were seen to be displaced. And although the errors in measurement were quite large, the displacement agreed with Einstein's prediction. The news was sent around the world, the *New York Times* put the story on its first page, and Einstein became an overnight sensation.

For our purposes, the important point about this episode is not so much the corroboration of general relativity as the fact that the displacement couldn't be measured very accurately under the eclipse conditions. After all, you're trying to take a photograph during a time when temperatures are falling sharply, causing the telescope to shrink. These photographs have then to be compared with others, and even under the best of conditions, photographic plates will distort a little as they are developed. In addition, the displacement itself is very small. It would correspond to the distance across a dime as seen from a mile away. The net result of all these difficulties is that from the time of Eddington's original work until the late 1950s there was scarcely any improvement in the accuracy of the measurements. This, in turn, meant that any theory that could manage to come within 10 or 15% of Einstein's prediction could not be ruled out on the basis of the data. And as margins for theorists go, this is as big as a barn door.



Don't get the idea that all of this came easy to Einstein, though. It is one of the little known oddities of history that among the theoretical predictions which Eddington proved wrong was one put forward in 1911 by...Albert Einstein! This was before he had worked out general relativity, of course, and the prediction was incorrect. In 1914 a German expedition started for the Ural Mountains to measure the light deflection during an eclipse there. But the start of World War I prevented them from carrying out their task. It's interesting to speculate how history might have been different if they had actually done their job and found Einstein's original (and now forgotten) prediction to be wrong.

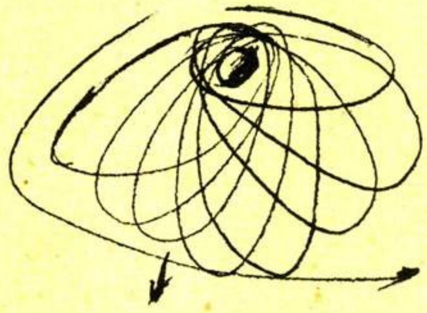
In the 1960s modern astronomy finally began to catch up with relativity. First, scientists at MIT increased the accuracy of the deflection measurement by bouncing radio waves off the planet Mercury just when it disappeared behind the Sun and then again later after its reappearance. By measuring the time between the emission of the radio signal and its return, the deflection of the radio waves by the Sun could be determined. The theory, of course, predicts that radio waves as well as light rays (and any other type of electromagnetic radiation) will be deflected by the same amount. This advance was important because, unlike visible light, radio waves are not obliterated by the Sun, so the experiment can go on whether there is an eclipse or not.

Then, in 1974-75, two scientists working at the National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia, brought things to their present state. They noticed that certain objects in the sky, called quasars, sometimes disappear behind the edge of the Sun in the same way that ordinary stars do. These objects are powerful sources of radio emissions, and it is possible to do deflection measurements on them without the benefit of an eclipse. Quasars may be galaxies in the process of formation, and they are so far away from us that the light and radio waves from them have been traveling for billions of years on their way to Earth. One particular quasar, called 0116+08 (hardly a euphonic title) goes behind the Sun every April 11. By using two parts of the Green Bank installation some 20 miles apart, it was possible to measure the deflection of the radio waves to an accuracy of 1%. When the data were in, Einstein was confirmed and a lot of other theories went by the boards.

This sequence illustrates perfectly the point we made at the beginning of this article. The techniques available to verify the predictions of general relativity were, by modern standards, quite crude for almost a half century after the theory came into being. During that time its widespread acceptance by the physics community was almost an act of faith. Only within the last decade has experimental technique improved to the point where we can truly speak of precision tests of the theory.

### The Gravitational Redshift

Modern experimental technique has also made possible precise tests of another effect Einstein predicted but which was never seen in his lifetime. If light is really affected by gravity, then it ought to lose energy if it has to climb up against the Earth's pull and gain energy if it "falls," just as ordinary objects do. Since light always travels at the same speed, this loss of energy shows up as a slight reddening in color for light moving upward, and a slight shift toward the blue for light moving downward. This effect, called the gravitational redshift, is so small that it wasn't until 1960 that scientists at Harvard University were able to detect it. But detect it they did, in precisely the amount that Einstein predicted.



This particular measurement should not, however, be taken as a triumph for general relativity in the same sense that the bending of light around the Sun was. This is because the gravitational redshift, although predicted by Einstein, is also predicted by any other theory that incorporates the principle of general relativity. So the experiment is something of a two-edged sword. It does certainly provide direct experimental evidence that the principle of general relativity is true, and this gives us a certain amount of philosophical comfort. On the other hand, it is unlike other tests because it doesn't help resolve the "shootout" over relativity now going on.

### The Precession of Mercury's Perihelion

The third "classical" effect of Einstein's theory, one he himself suggested, was actually detected during the nineteenth century, but it remained something of a mystery until 1915. It has to do with the orbit of the planet Mercury. We usually think of the orbits of the planets as being circular in shape, but they are actually slightly elliptical. This means there will be a time during each planet's "year" when it is closest to the Sun, and a time when it is farthest away. If it gives you any comfort, for example, our own Earth is a little closer to the Sun during winter in the northern hemisphere than it is during the summer. The point at which a planet is closest to the Sun is called the *perihelion*.

Detailed observations of the closest planet to the Sun (Mercury) during the late nineteenth century revealed a rather strange fact. It was discovered that during each orbit of the planet (a Mercury "year" is about 89 days), the perihelion moves ("advances") by about 100 miles. After two "years," the perihelion will have moved 200 miles. All but about nine miles of this "yearly" advance could be explained in terms of the gravitational pull of Venus, the Earth, and Jupiter on Mercury, but the small unexplained residue remained one of the puzzles confronting astronomers at the turn of the century.

Einstein showed that the effects of general relativity near a large body like the Sun would produce precisely this sort of effect on nearby planets. Mercury, being the closest and lightest planet, shows the effects most markedly, but perihelion advance can be measured for Venus, the Earth, and Mars as well. In fact, the accuracy of this measurement has been improved upon in modern times by using the radar ranging techniques mentioned earlier to determine the location of the inner planets. At the present time, all of these numbers seem to support Einstein.

Not all scientists, though, accept this interpretation of the results. The problem is that the actual amount of perihelion advance, once the general rotation of the solar system is taken into account, is over 500 seconds of arc per century, and all but 43 seconds of this is accounted for by standard Newtonian effects. This means that even a very small error in the orbital dynamics part of the analysis — one effect left out or put in incorrectly — can throw the agreement between general relativity and experiment completely off. In 1967, for example, R. Dicke of Princeton (the author of one of the competing theories of gravitation) made some observations which indicated that the Sun is not a perfect sphere, as had been previously supposed, but was slightly flattened at the poles. If true, this would have the effect of adding a hitherto unsuspected contribution to the perihelion advance and would reduce the "unexplained" portion to 39.6"/century, well below that predicted by Einstein. Dicke's results are not universally accepted because they contradict other precision optical measurements and because, even if they are correct, there is no guarantee that a flattening of the optical image of the Sun corresponds to the type of gravitational effect he calculates. Nevertheless, the result does mean that the interpretation of the perihelion shift as a strong support for general relativity is, at the very least, less strong than we would like.

So the bottom line at present is that the only unambiguous and reasonably precise experimental confirmation of general relativity is the NRAO measurement of the bending of radio waves. In other words, we accept general relativity on the basis of a single observational test. This is why scientists are now putting a great deal of effort into devising new tests of the theory, both in space satellites and in laboratories. When all is said and done, general relativity will probably be vindicated, but for the present we must entertain — with an open mind — a seemingly heretical thought: Maybe in this case Einstein was wrong!

*James S. Trefil, a Professor of Physics at the University of Virginia, specializes in elementary particle physics, fluid mechanics, and cancer therapy. He is the author of* **Physics as a Liberal Art** *(1977) and his latest book is* **Physics for the Life Sciences** *(to be published by Prentice-Hall).*

# ASTRONOMY IN FOCUS

Sir / I would like to comment on Mr. Ordway's letter in the October 1979 issue regarding the reasons that an aggressive manned space effort has not been undertaken since Apollo. Mr. Ordway states that the climate was not propitious, but fails to mention the reason.

The sad fact is that the average American was not intelligent enough to understand just how immense Apollo was or how great its potential could have been. It was a program betrayed eventually by the man on the street as well as the man in the White House.

While President Nixon was taking full advantage of the opportunity to "look good" by talking to the Apollo 11 astronauts on the Moon, he was busy slashing the NASA budget — insuring that a grim future awaited NASA.

I don't feel sorry for Americans and their apathy toward space exploration. I do feel sorry for the scientists, technicians, and engineers who put in so much hard work, as well as the three astronauts who gave their lives so that this country could gain predominance in space exploration.

Maybe the American people didn't deserve Apollo. They might have been just as happy with a new TV, carpeting, or some other materialistic amusement.

David Fabrizio
Stratford, CT

Sir / Please allow me one last reply in the debate over the SPS.

Planetary chauvinists seem to feel the need to create a utopia on Earth, to purify ourselves, before we put our "corruptive imprint" on the sacred heavens. They fear the future and feel guilty for the past and the present. This sentiment is perfectly correct but profoundly useless.

Planetary chauvinists have their roots deep in the good earth and the lights in the sky are magic to them. They will never know the magic of being a citizen of the Galaxy.

What to the planetary chauvinist may seem like "techno-messianic" zeal, lawless commercial avarice, nightmare energy weapons, and "extravagant, hopelessly unrealistic ambitions" will nevertheless probably become reality. The greedy will fly out to plunder the universe. People like me, who just want to go up there to enjoy the view, will probably get trampled in the rush.

From an anthropological point of view, technology is a natural fact of human existence. It solves problems and makes more problems. The exploitation of space may solve some of our resource-related problems. Earth may be saved from pollution and overcrowding. But there is no guarantee. All I can say for sure is that space exploitation and the SPS have no bearing at all on the condition of mankind's immortal soul. Our "corruptive imprint" will fall on any real estate we can reach. It has been this way for a million years. The process is not bad, not good, and not alterable. It just is.

I thank ASTRONOMY for printing my first letter, and for omitting my inept discussion of SPS waste heat problems.

Warren Merkey
Gainesville, FL

Sir / I wonder if any of the proponents of the SPS have bothered to calculate the "buy-back" of energy required to produce and deploy the SPS. Perhaps like many of the proposed solutions to the energy problem, the "buy-back" would take longer than the useful life of the system.

I am reminded of a plaque which hung on the office wall of George Stoner, late vice-president of Boeing Aerospace Division which, I believe, speaks to the matter:

"The hypothesis that nothing is impossible carries with it the pitfall corollary that nothing is ridiculous."

Alvin J. Jarvis
Hastings, FL

Sir / I enjoyed the letters of Baudino, McGuire, and Gatschet on the subject of the SPS proposals.

I would only add that the SPS, rather than being a great boon to astronomy and space exploration, would have the opposite effect. By causing us to live in "perpetual daylight" the attraction of the stars would vanish from human consciousness. We would be psychologically trapped in our manmade cocoon.

Those who advocate the SPS are not advocating progress. They are calling for a return to the womb.

Fr. Robert Allen Buss
Dickinson, ND

Sir / We have been subscribers to your magazine for a few years. When a question was raised in a classroom about the planets Pluto and Neptune, I looked over the latest issues of ASTRONOMY, but I couldn't find what I was looking for. Someone had said that recent findings place Neptune farther away than Pluto. My books here, including *World Book Encyclopedia*, describe Pluto as the planet most distant from the Sun.

My question to you is, have there been recent findings about the distances of Pluto and Neptune which place Neptune farther away than Pluto? If the findings are too recent to have been published, please confirm the above or state there are no new findings of this kind.

Mrs. Oliver Duhe, Jr.
New Orleans, LA

*Mrs. Duhe / The orbit of Pluto is highly elliptical, and at times the outermost planet swings in closer to the Sun than Neptune. As of January 1979, Pluto entered that part of its orbit which brings it closer to the Sun than Neptune, approaching perihelion (minimum distance) in 1989. Thus, Neptune will be the outermost planet until 1999 — a total of 20 years out of Pluto's 248-year orbital period. Pluto will reach its greatest distance from the Sun (aphelion) in 2113. (See diagram on p. 8, ASTRONOMY, December 1978.)*

Sir / I have been puzzled by an article about a googol. It is the largest noted mathematical number.

You have stated that there isn't anything as great as a googol. I believe that the number of inches in space is as great or greater than a googol. Could you prove there is nothing in the universe larger than a googol?

Richard J. Wilton
Black River, NY

*Mr. Wilton / A googol is defined as* $10^{100}$ *— or 1 followed by 100 zeros. The radius of the visible universe is estimated to be no greater than 20 billion light-years* ($2 \times 10^{10}$ *light-years). One light-year equals nearly 6 trillion miles* ($5.9 \times 10^{12}$ *miles), or* $3.7 \times 10^{17}$ *inches. Therefore, the volume of the visible universe* ($4\pi R^3/3$) *in cubic inches is about* $1.7 \times 10^{84}$ *inches*$^3$ *— nowhere near a googol.*

*What about cubic millimeters? Not much better — the volume of the universe is about* $2.8 \times 10^{88}$ $mm^3$*, which means it would take over 350 billion universes the size of ours to contain a googol of cubic millimeters.*

*But a googol is still not the largest number defined. That honor goes to the* googolplex*:* $10^{googol}$*, or 1 followed by a googol of zeros!*

Sir / I have recently acquired an interest in photographing minor planets and determining their orbits with a programmable calculator. Do you have any information concerning the locations of many of the lesser known asteroids, excluding the "big four"?

Paul Severance
Kasson, MN

*Mr. Severance / The main source for asteroid position predictions apart from those given in the* **American Ephemeris & Nautical Almanac** *for Ceres, Pallas, Juno, and Vesta, is the* **Ephemerides of Minor Planets,** *published annually by the Academy of Sciences of the U.S.S.R. The text is in English and Russian, but anyone reading English only would have little trouble using it. Not commonly found, you may have to look it up in a large university or public library. Another possibility is the* **Handbook** *of the British Astronomical Association. This publication doesn't list as many asteroids, but finding a copy may be somewhat easier. Try a library or astronomy club. Or write the B.A.A. at Burlington House, Piccadilly, London W1V 0NL, England.*

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## Ooops!

Due to an error by the author, several of the illustrations in the article "Using Earth as a Radio Telescope" (October 1979) were incorrectly credited. The photographs on pages 6-7 and 13 were made at the Rheinisches Landesmuseum, Bonn (West Germany) by staff of the Max-Planck-Institut für Radioastronomie. Only one of the six observations contained data from Westerbork (Leiden Observatory), the others being observations made by the Max-Planck-Institut's 100-meter radio telescope in Effelsberg.

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behind
the scenes

## a few changes...

If you've gotten this far, you've noticed the change: ASTRONOMY has a new look for 1980. Most of the type in the magazine, "body copy" in magazine lingo, is no longer Century Schoolbook (which we formerly used), but a close relative of Optima, the elegant face used in the ASTRONOMY logo. We think you'll like its looks and it's very easy to read.

We've replaced the old department stops for Gazer's Gazette, Photography in Astronomy, and Equipment Atlas (a bit shopworn after six years) with a cleaner, more open design that combines the title and name of the department. Also redesigned are the headings for Astro Mart, Astronomy Reviews, Forum, & In Focus.

And tucked away in a thousand little nooks and crannies, are other more subtle changes designed to keep ASTRONOMY as modern and up-to-date in appearance as ASTRONOMY's founder Stephen Walther intended it to be.

Behind these changes is an important change in personnel: we've added Art Director Thomas L. Hunt to our staff. Tom formerly worked for Reiman Associates, the publisher of four very successful farming magazines, where he had three years of valuable experience as an associate artist. He graduated from the University of Wisconsin in Milwaukee in 1976 with a degree in Visual Communications. Tom has been an ASTRONOMY reader for quite some time — he's owned a small refractor since his junior high school days — so he's brought a personal appreciation of the beauty of the night sky with him to ASTRONOMY.

Tom's specialty, if you can truthfully say that such a versatile person has a specialty, is type design. He's also a skilled commercial artist, a photographer, a gourmet cook, and for relaxation he enjoys designing and building fine furniture. Tom is responsible for maintaining the "look" of ASTRONOMY — making sure every single page is as good as it possibly can be. We're pleased to have him on our staff.

Sincerely,
Richard Berry
Richard L. Berry

**Webb Society Deep-Sky Observer's Handbook**
edited by Kenneth Glyn Jones
Vol. I: **Double Stars**, softbound, 120 pages, $7.95
Vol. II: **Planetary and Gaseous Nebulae**, softbound, 149 pages, $7.95
Enslow Publishers (1979)
[publisher's address: Box 301, Short Hills, NJ 07078]

These exciting new observing guides are the first two in a projected series on various classes of deep-sky objects compiled by the Webb Society in England. Founded in 1967 by amateur (and some professional) astronomers in that country, this organization's membership has become international in scope and is open to all who are seriously interested in this branch of astronomy. Named in honor of the Reverend T.W. Webb, it endeavors to foster the study of objects beyond the solar system by amateurs in the grand tradition of that great observer and mentor of stargazers.

Volume I first appeared in 1975 and Volume II in 1978 under the Society's imprint. Being reviewed here are the very same ones in a new joint American-British edition, published concurrently in the United States by Enslow Publishers and in England by Lutterworth Press. Under the able editorship of the noted Messier authority Kenneth Glyn Jones, F.R.A.S., this series is being offered to observers with the following stated objectives: "We hope that these volumes will enable the reader to extend his abilities, to exploit his telescope to its limit, and to tackle the challenging difficulties of new fields of observation with confidence and success."

Each *Handbook* is a complete self-contained reference work on the particular class of deep-sky object it treats. Among the wide range of topics covered are historical perspectives, basic physical data and characteristics, practical observing techniques (both visual and photographic), and the construction of various accessories such as micrometers and spectroscopes. Also included are extensive listings of sample objects to locate and study, and a good working bibliography for further reading. In all, Volume I surveys some 522 double and multiple stars, while Volume II treats 89 planetary and 93 diffuse nebulosities.

Perhaps the most valuable feature of the *Handbooks* are the many observations on which they are based. In the case of double stars, for instance, reasonably recent values of separations and position angles are provided for more than 500 pairs — ones that in some cases hadn't been measured for half a century or longer. And readers of ASTRONOMY's Star Dome column will welcome the fascinating descriptions of the assorted nebulae, which have been derived from visual impressions at the eyepiece.

As with any undertaking of this magnitude, there are some things about the *Handbooks* that may disappoint some of their intended users. As one striking example, Volume II is illustrated with dozens of fine telescopic sketches of diffuse and planetary nebulae (some of which were made with telescopes as large as 100 inches in aperture by David Allen, one of the Society's professional members), but not one drawing of a double or multiple star is to be found anywhere in Volume I. This is a significant omission in view of the serious lack of such illustrations for these objects in virtually every observing guide in print today.

Those drawn by the aesthetic lure of deep-sky observing will also probably sense a certain lack of warmth in the *Handbooks* resulting from their semitechnical nature. In recording the colors of double stars, for example, a numerical scale (that of Hagen, ranging from a -3 for pure blue to +10 for pure red) is recommended in place of writing them out. As an active visual observer will tell you, no number can ever convey the rich spectrum of heavenly hues displayed by these colored jewels of the sky. (Fortunately, in the notes accompanying the object listing, colors are given a letter abbreviation — "o" for orange, "b" for blue, etc. — that is much easier to relate to than a number.)

Also, because these books have been reproduced directly from type script, the familiar Greek-letter designations for both stars and observers' names are not used. Instead of the traditional "Σ" before Wilhelm Struve's double stars in the catalog section of Volume I, we find an "STF" prefix, and so on. Such changes in style will seem strange and awkward to those accustomed to the original system.

This reviewer takes issue with one statement on the cover of both volumes of the *Handbook*: that these are "intended to be a replacement" for Webb's *Celestial Objects for Common Telescopes*. First published in 1859, this classic work is still in widespread use by observers today thanks to a Dover reprint edited by Margaret W. Mayall. While admittedly out-of-date in terms of its basic astronomical knowledge, and "more of historical than practical interest to the amateur of today," Webb's masterpiece remains unique. Its warm and charming eyewitness accounts of celestial wonders can never become outdated — they are timeless.

In this same vein, these new observing guides in no way compete with or duplicate existing references on deep-sky objects — even ones as comprehensive as Burnham's *Celestial Handbook* (reviewed in the July 1979 issue of ASTRONOMY). Instead, this series supplements them as working

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observers' manuals offering valuable and often hard to find "how to" information for serious telescopists. And in this role, the *Handbooks* succeed admirably.

The first two Webb Society *Deep-Sky Observer's Handbooks* are a truly superb addition to the observational literature for today's amateur astronomer. Hopefully they will go a long way toward stimulating useful work by such enthusiasts — especially in badly neglected fields like measuring double stars (where only a handful of professionals face the hopeless task of following the 65,000 pairs now in catalogs). These are important books, for they bring with them the bright promise of a cure for the idleness that afflicts many fine astronomical telescopes today. *James Mullaney.*

**Geology of the Planet Mars**
edited by Vivien Gornitz
414 pages, hardcover, $39.50
Dowden, Hutchinson & Ross (1979)

This book is one of the publisher's "Benchmark Papers in Geology" series. It is a collection of 36 papers from professional journals on the subject of martian geology. The earliest paper is dated 1956, but the bulk are from the early 1970s to the present. A 23 page introduction provides an historical overview, and each section of the book is a detailed commentary on the papers within it. Though the material was written for the working scientist, any interested lay person can browse through the volume and get a good sense of how the problems and ideas on martian geology have evolved.

**What's Up?**
by David H. Olson
64 pages, spiral bound, $7.95
(order from author at 1787 W. Minnehaha, St. Paul, MN 55104)

Subtitled "an hourly guide to selected astronomical objects", Mr. Olson has put together a guidebook of objects at or near the meridian for each hour of sidereal time. The guide is produced in versions for latitudes 30°, 35°, 40°, 45° and 50° north. A table is provided which allows easy conversion from clock time to approximate sidereal time for any day in the year. In each hourly section, he lists objects (including the whole Messier list) arranged by type. In addition to the expected R.A. and Dec., altitude and azimuth are given also, as are angular diameters where appropriate. Some simple sky maps are at the end.

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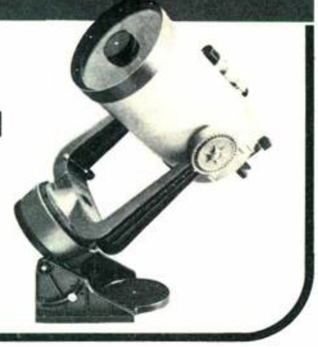

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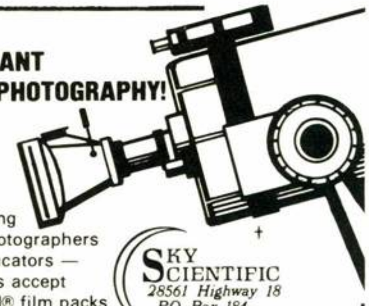

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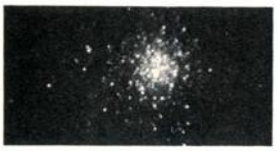
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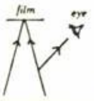

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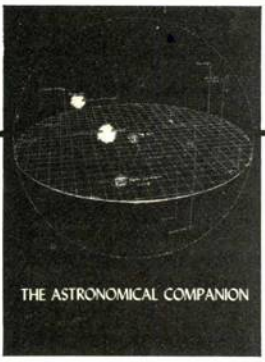

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ANNOUNCEMENTS — The Probe One Society is looking for new members. Deals with science fiction/astronomy fact (ages 13-35). Those that wrote before, do again, will explain. For information write William Chriscoe, Rt. 4, Box 1, Burlington, NC 27215.

ANNOUNCEMENT — The Edmonton Centre of the Royal Astronomical Society of Canada meets on the 2nd Monday of each month (except July and August) at the Public Library. For information contact RASC, c/o Queen Elizabeth Planetarium, Coronation Park, Edmonton, Alberta, CANADA.

ANNOUNCEMENT — 26th National American Radio Relay League Convention will be held in Seattle, Washington July 25-27, 1980. Theme is "World Friendship Through Amateur Radio" and includes world-wide speakers, seminars, manufacture's exhibits. For registration and information write: 1980 AARL National Convention Committee, P.O. Box 68534, Seattle, WA 98168.

ANNOUNCEMENT — Columbus Astronomical Society, Columbus, Ohio, meets 2nd Saturday, 8 p.m. every month September through May (except December) at Battelle Memorial Institute, 505 King Ave., Room G. Call Robin de Santos or Brent Archinal for information (614) 299-9464.

ANNOUNCEMENT — The Astronomical Society of Greater Hartford, Connecticut, meets on the 3rd Wednesday of the month at 8 p.m. at the Gengras Planetarium, 950 Trout Brook Dr., West Hartford, CT. Public is invited. For details call (203) 633-1829.

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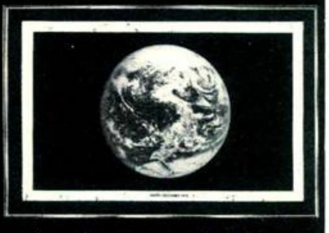

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ANNOUNCEMENT — Willingboro Astronomical Society meets Fridays, 8:30 p.m., Willingboro Municipal Building, Salem Road, Willingboro, NJ. Call Philip A. Webber for directions and information. Phone (609) 871-7438.

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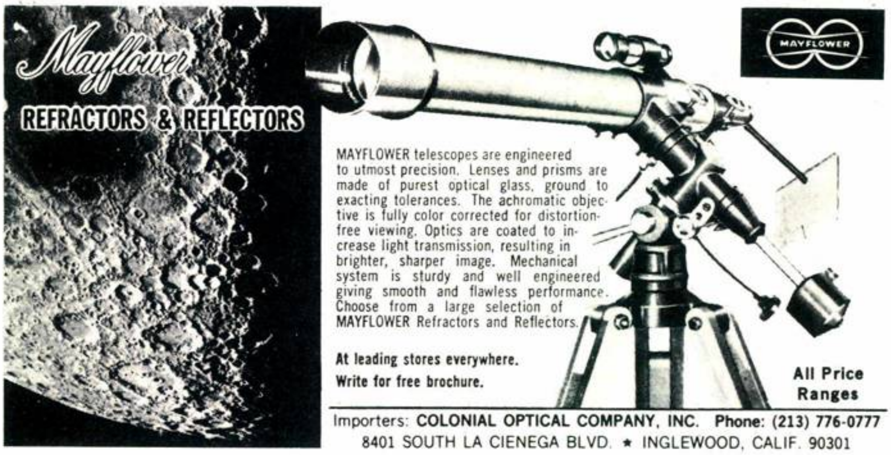

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# january: close-up on perseus

### by
### James Mullaney & Dewey Schwartzenburg

The Milky Way is a striking phenomenon in the starry sky. Although it covers only about one-tenth of the area of the heavens, it contains nine-tenths of all the stars. Sweeping around the entire celestial sphere like a wide belt, it is inclined over 60° to the celestial equator so that its southernmost stretch isn't visible from the United States, never rising above the horizon.

Long a mystery, its true nature was ascertained only in this century. Ancient and primitive peoples tended to think of the Milky Way as quite literally a "way" or road, taken by departed souls on their journey to heaven. But by the nineteenth century, astronomers began to suspect that the Milky Way was a sign of some vast structuring of the cosmos, a scheme of organization that just barely eluded their understanding. Agnes Clerke, for example, wrote in the last century: "All the contents of the firmament are arranged with reference to it. It is a large part of a larger scheme exceeding the compass of finite minds to grasp in its entirety."

Now of course we know what the Milky Way truly is, and it is enormously more vast and complex than even the most speculative of the nineteenth century astronomers imagined. The Milky Way we see at night is only a small part of the huge disk of stars, nebulae, gas, and dust we now know swings solemnly through the emptiness of intergalactic space, because most of this giant system (including its center, the densest and most crowded part) is hidden from our sight by obscuring interstellar clouds.

Furthermore, we know that our Galaxy is only one of uncounted billions of such systems scattered across unimaginable distances through a universe far, far larger than any astronomer before this century would have believed possible. Yet with only a few exceptions, literally everything we can see in the sky with our naked eyes is a part of our own Galaxy — a close neighbor on the cosmic scale of things.

Different parts of the Milky Way are seen at different times of the year. The pale gleam of the winter Milky Way can be seen arching high across the sky on January evenings. Stretching from the northwest to the southeast, the Milky Way at this time of year is not as bright and dramatic as it is in late summer, when the great starclouds of Sagittarius, Scutum, and Cygnus shine above us. In fact, the great circle of the Galaxy almost vanishes in Auriga, fading down to the merest glimmer. But the winter Milky Way still has much to delight the naked-eye observer.

In the south the Milky Way flows through the "oasis" of the winter circle — a grouping of brilliant stars centered on red Betelgeuse. Beginning nearly straight overhead with Capella (magnitude 0.2), the circle continues down to the west through Aldebaran (1.1) and Rigel (0.3) to Sirius, at -1.6 the brightest star in the sky. Up again toward the east, the circle is completed by Procyon (0.5), Castor (1.6), and Pollux (1.2). In the center of this stellar oasis the red giant Betelgeuse shines at magnitude 0.9. In fact, the winter circle includes seven of the fifteen brightest stars in the whole sky.

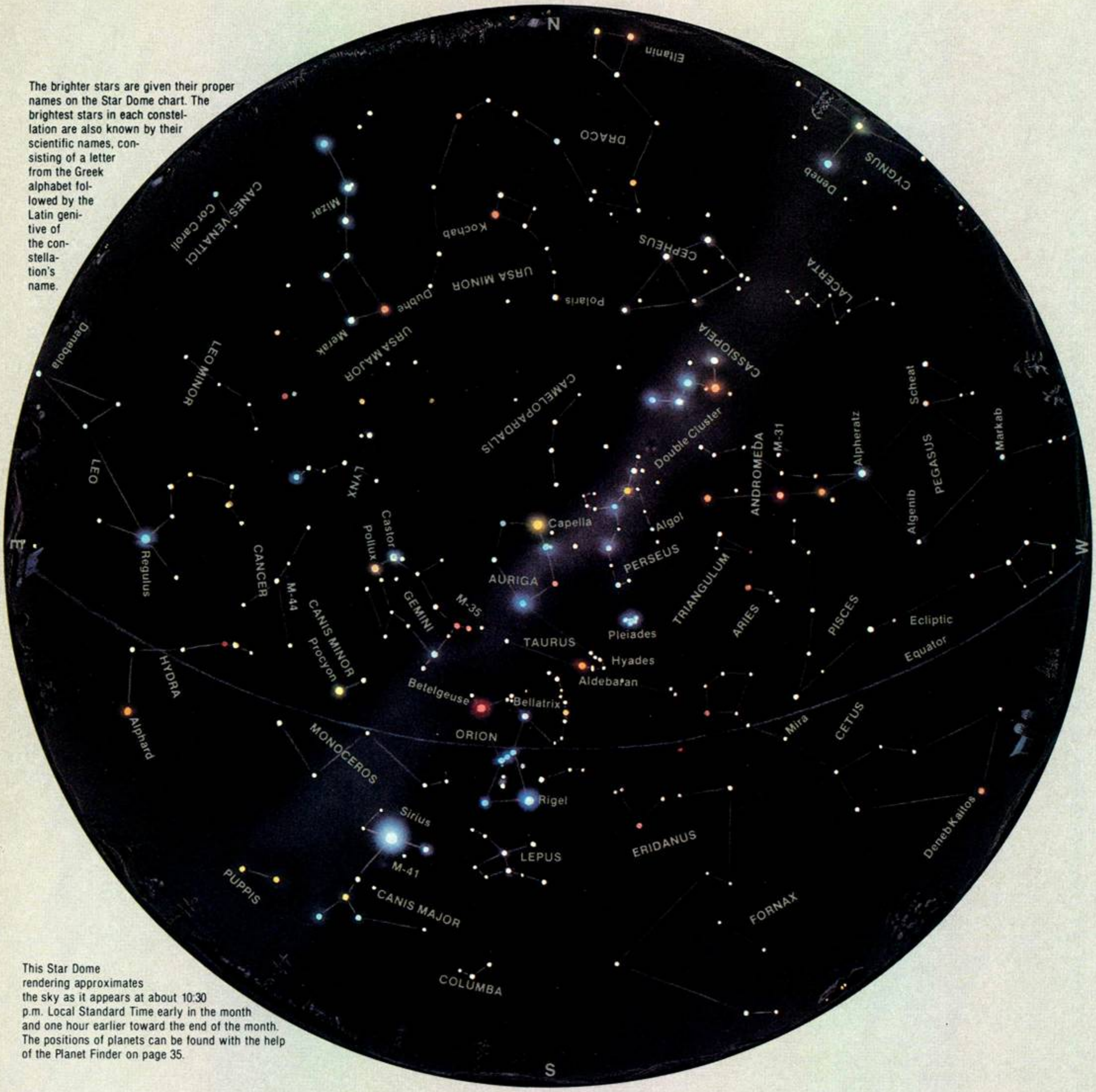
When we look at this part of the Milky Way, we are gazing in a direction exactly opposite the center of the Galaxy. Therefore all of the stars in the winter circle lie in the outer reaches of our Galaxy, farther from its center than the Sun. The great star clusters of the Hyades and the Pleiades, the Great Nebula in Orion and the eclipsing binary Algol, all swing through the Galaxy in orbits larger than that of our solar system. It isn't surprising that the Milky Way becomes such a pale trickle in this part of the sky when we realize that here we are looking out through the sparsely populated outer regions of the galactic disk. The star density here is ten times less than it is in Sagittarius, where the center of the Galaxy is found. The true surprise, though, is that the view in the other direction, toward the galactic center in Sagittarius, is not even more dramatic and overwhelming than it is. The reason, of course, is that our view of the center of the Galaxy is obscured by the vast clouds of dust and gas between us and the center, one of which causes the "Great Rift" in the Milky Way between Cygnus and Scorpius.

As noted above, everything we can see in the sky with our naked eyes is a part of the Galaxy — with a few exceptions. One of these can also be seen on January evenings. M-31, the Great Galaxy in Andromeda, is visible with the naked eye in the west just below the belt of the Milky Way. When we gaze at this faint patch of light, we are looking out past the great disk of our own Galaxy across a vast gulf of intergalactic space to another "island universe" — a near neighbor in the universe as a whole, but to us incredibly distant.

Thousands of years ago, when the world was thought to be much smaller than we now know it to be, a poet wrote in Psalm 8:

> I look up at the heavens,
>   made by your fingers,
> At the moon and stars
>   you set in place...
> Ah, what is man that you
>   should spare a thought for him,
> The son of man that you should
>   care for him?

When we look up now in the light of modern knowledge at the Milky Way stretching across the sky, and beyond it to other galaxies, our humility must be far greater than that of the psalmist. The enormous scale of the cosmos revealed by modern astronomy only a few decades ago is truly overwhelming.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The brighter stars are given their proper names on the Star Dome chart. The brightest stars in each constellation are also known by their scientific names, consisting of a letter from the Greek alphabet followed by the Latin genitive of the constellation's name.

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month and one hour earlier toward the end of the month. The positions of planets can be found with the help of the Planet Finder on page 35.

# close-up

### Perseus

Crowning the zenith on frigid January evenings is the glittering celestial wonderland of Perseus — a sky area of 615 square degrees. This royal figure is exquisitely set against the rich and radiant backdrop of the winter Milky Way. As a result, virtually anywhere we point our telescopes here we encounter apparent groups and clusters of stars. Few of these will be found on existing charts and lists, but they nevertheless provide thrilling vistas for the stargazer who ventures forth at this time of year.

### Alpha (α) Persei Association

The starry sprinkling about Alpha Persei which has elicited so many glowing comments from the classic observers actually represents an officially recognized class of celestial objects known as a *stellar association.* These are very loosely-knit gatherings of stars too scattered to be considered as normal open clusters, but still gravitationally bound together and moving through space as a unit. While many are to be found throughout the heavens, these associations are rarely observed by deep-sky observers — who seem largely unaware of their often surprising beauty.

You won't find the Alpha Persei association in our table of selected objects nor on most lists of telescopic targets. This is because it is difficult to specify such parameters as apparent magnitude and angular size (or even coordinates!) for such large amorphous groupings as these. Yet, it is a striking sight in low-power, wide-field instruments such as binoculars and richest field telescopes. The effect is all but lost in typical telescopic views, however, which probably accounts for the neglect accorded this object and others of its class by amateurs.

One of the few published visual accounts of this unusual clan is that by

Robert Burnham, Jr., who noted: "Lying directly in the Milky Way, Alpha Persei is the center of a fine field of stars which forms a rich and brilliant group for small telescopes."

Alpha Persei itself is a highly luminous F5-type supergiant sun lying some 570 light-years away which shines in our sky at magnitude 1.8. The association encompassing it contains over a hundred member stars and is strung out over several degrees of the heavens. Together they quietly await your inspection the next clear night.

### Beta (β) Persei

Our next offering can also be enjoyed with the unaided eye, binoculars or wide-field telescopes. This is the famed eclipsing variable star Beta (β) Persei — better known as Algol. The most popular and visibly conspicuous member of its class, this star's periodic dimmings were known to the Arabs and others of antiquity, who called this ominous object Al-ghul, the "demon star."

Algol is not an intrinsic (or "real") variable star but rather a very close double star system in which a "dark" G-type sun passes in front of a bright B-type one, partially blocking its radiance. The orbital plane of the pair happens to lie nearly in our line of sight from Earth; if it didn't, the stars would circle each other without eclipses. Thus, from most other vantage points in space, Algol wouldn't be recognized as a variable star at all.

Much of the time, the combined light of this system is steady at magnitude 2.1. Once every 2 days 21 hours, however, Algol sinks more than a magnitude to 3.4 in just a few hours' time. Minimum light lasts only about 20 minutes, followed by an equally rapid recovery, the entire eclipse cycle taking some 10 hours to complete. A good reference star by which to gauge these variations is nearby Mirfak, which shines at a constant magnitude of 1.8.

It's fun to see if you can catch the demon star "winking" at you across space from its distance of more than 100 light-years. Should you see it changing in brightness, gaze at it in awe, for before your very eyes and without the slightest optical aid, you

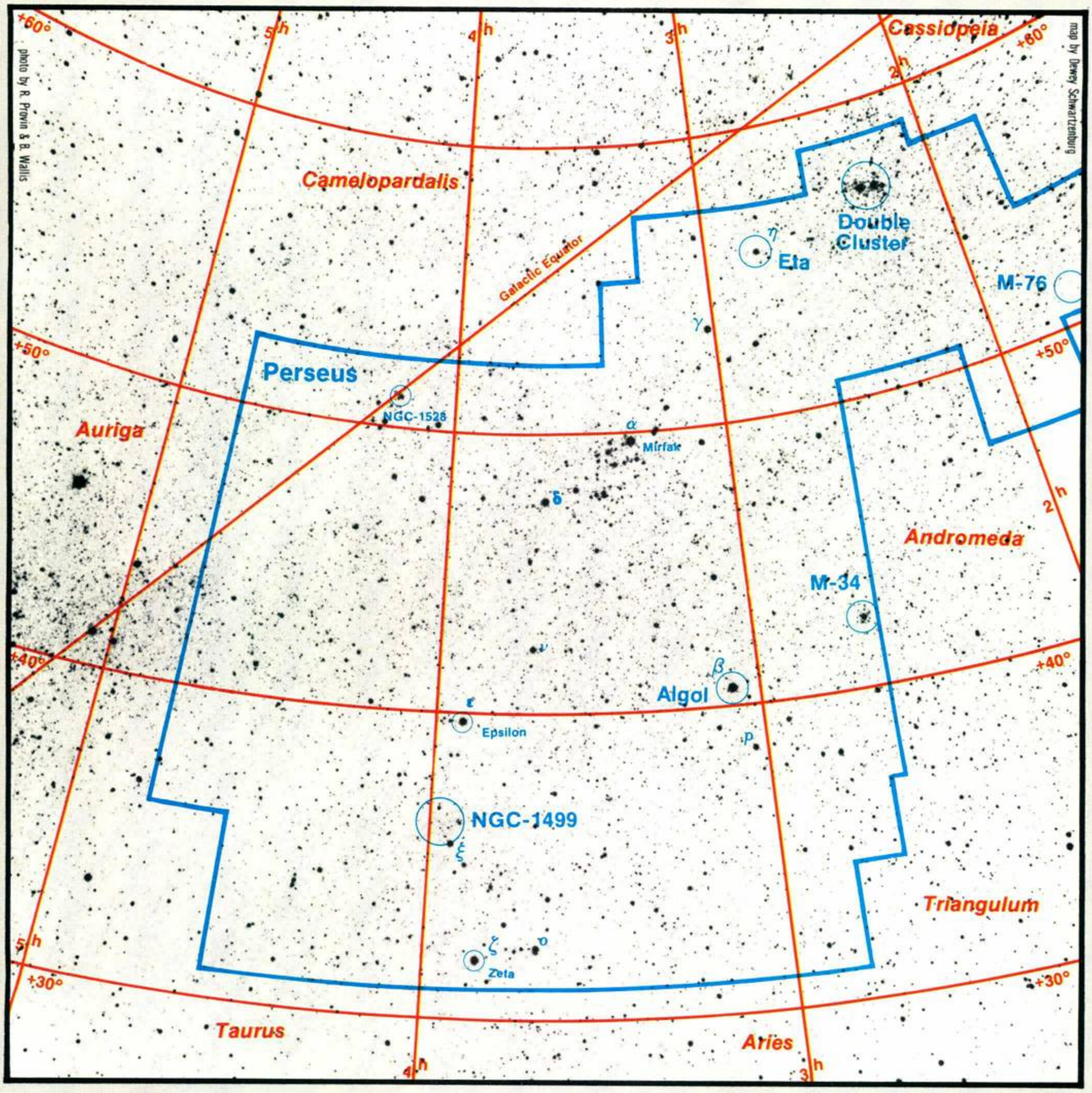


photo by R. Provin & B. Wallis

map by Dewey Schwartzenburg

are witnessing the mutual revolution of two mighty suns about one another.

At least one and possibly several other unseen companions of Algol are suspected on the basis of astrometric and spectroscopic studies, resulting in "an enormously complex system" in the words of the great double star observer Aitken. Telescopically, there are a number of very faint visual attendants, the brightest being a 10.5 magnitude star some 80 seconds of arc distant near position angle 190° (nearly due south of the primary).

### Eta (η) Persei

Typical of the great number of double and multiple stars in this month's region having bright primaries and faint companions is Eta (η) Persei. Easily visible to the unaided eye, a line extended from Alpha through Gamma (γ) Persei points directly at it, not far from the Double Cluster (discussed later).

Here we find 3.9 and 8.5 magnitude suns a roomy 28 seconds apart in position angle 300°. Also present is a fainter star 66 seconds distant at 270°, which closer inspection reveals to consist of two 10th magnitude objects 5 seconds apart near 115°.

Three stars are evident here in a 3-inch glass at 45 power, while a 4-inch at 100 diameters reveals all four components. A distinct color contrast can be seen in such instruments between the two brightest members, the primary appearing deep yellow or orange and the 8.5 magnitude star a rich blue. Six-inch and larger apertures enhance the tints, and make the close faint duo more definite.

Webb mentioned at least five faint companions to Eta, most of which are probably surrounding field stars. However, the 8.5 magnitude star is drifting through space with the primary, forming a common proper motion pair. Eta itself is a K3-type sun (agreeing well with the visual color impression above) and is about 540 light-years from us. If seeing this object excites you, several others like it are given in the table — each one having its own unique visual appeal to captivate the celestial explorer.

### M-76

A well-known but elusive deep-sky

wonder lurks near the Perseus-Andromeda border, just a degree north and slightly west of 4th magnitude Phi (ϕ) Persei. This is the dim planetary nebula M-76, regarded by many as the faintest and perhaps most difficult of all the entries in Messier's famed roster. If you've already succeeded in finding it, do you agree with this assessment? If you haven't seen it yet, why not give it a try the next dark (moonless) and transparent night.

A typical finder will completely fail to show its presence, so M-76 is best found by sweeping directly with a telescope using a low-power, wide-field eyepiece. A 4-inch glass at 45 power reveals a faint elongated glow on a good night using averted vision, while a 6-inch at 50 to 100 diameters makes its rectangular form definite. Larger apertures allow glimpses of structure within the nebulosity itself.

M-76 glows softly at 11th magnitude and measures 140 by 70 seconds (or roughly 2 by 1 minute) in apparent size. It is somewhat pinched in the middle and brighter at either end, reminding some observers of a smaller version of the well-known Dumbbell Nebula (M-27) in Vulpecula. For this reason, it is often referred to as the Little Dumbbell or Barbell Nebula. Another name given to it is the Corkscrew Nebula, from its appearance in large instruments and on photographs.

Looking like a double nebula in some telescopes, M-76 carries a dual NGC designation (650 and 651). It is classified as "irregular" in form among the planetaries and has a very faint 16th magnitude central star. Does this object look double in your telescope on a good night?

Burnham described M-76 as a "box-shaped mass" and Mallas a "rewarding object" in his 4-inch refractor. Webb found it a "pearly white nebula, double, curious miniature of M-27,..preceding (lobe) a little the brighter." Other observers seemed puzzled by its true nature; Herschel included it in his Class I (bright nebulae) rather than Class IV (planetary nebulae), and Lord Rosse thought it spiral in form. Even a later observer like Barns seemed fooled, as his description indicates: "Double spiral nebula, joined, with ring."

Like most members of its class, the distance to this cosmic impersonator is uncertain. Values for M-76 range from less than 2000 light-years to more than 8000, the higher figures being considered more likely in view of its size and brightness. Planetary nebulae are sometimes referred to as "stellar crypts," since they are thought to represent the closing stages of stellar evolution. For those who would come to pay their respects, they will find this one buried in the dense stellar forest of the Perseus Milky Way.

### NGC-1499

If you succeeded in locating M-76, you might like to try an even more elusive and difficult object. This is the large and very faint diffuse nebulosity NGC-1499, better known as the California Nebula from the uncanny likeness of its outline to that of the state (see photo on page 37, November 1979 ASTRONOMY). Often pictured in wide-angle observatory photos of this region, it is seldom even searched for by visual observers.

This ghostly smear of luminescence measures some 145 by 40 minutes (or nearly 2½° x 1°) in size and is so spread out that no definite magnitude can be assigned to it. Centered just 1° north of 4th magnitude Xi (ξ) Persei, slow sweeping with large aperture binoculars or wide-field telescopes will reveal its presence to a trained eye on a dark transparent night. Scanning back and forth across it is the only way to glimpse its entire outline with normal telescopic fields of view. A 6-inch reflector at 30 power will show its gossamer glow against a rich stellar background on a good night.

### M-34

After straining your eyes (and patience) trying to detect M-76 and NGC-1499, treat them to M-34 — one of Perseus' bright, splashy open star clusters. Situated roughly midway between Algol and Gamma Andromedae, this sparkling clan can be seen with the unaided eye under dark skies and is a fine sight in binoculars and finders.

M-34 is a rather loose concentration of some 80 member stars spread over an area of sky the apparent size of the full moon (about 30 minutes of arc). Its integrated or combined light is equal to that of a 5.5 magnitude star, accounting for its visibility without optical aid. Most of its gems are blue-white in color and are arranged in pairs radiating outward from a boxlike pattern at its center.

Smyth called this object "a scattered but elegant group" and Webb a "very grand low-power field, one of the finest objects of its class." Burnham pointed out that M-34 resembles M-36 in Auriga, while Mallas remarked: "A very fine cluster which 7 x 50 binoculars will resolve quite well" and "the main stars form a distorted X." As usual, Barns outdoes everyone with his exalted account: "A celestial aegis hung aloft in splendor!"

M-34 lies approximately 1500 light-years from us. This stellar commune is truly a superb sight in 2 to 6-inch aperture scopes, but as telescope size increases (and field of view decreases), its splendor fades rapidly. In a 13-inch refractor at 150x and 1/3° field of view, this object is disappointing. As we've noted here before, some celestial showpieces look better in humble backyard instruments than in the world's largest telescopes.

### The Double Cluster

Saving the best for last, we conclude our survey of this month's region by examining one of the grandest telescopic sights in the entire heavens. This is the famed Double Cluster in Perseus — NGC-869 and NGC-884, or h and Chi (χ) Persei as it appears on lists and star charts (see photo on page 49, October 1979 ASTRONOMY).

Easily spotted with the unaided eye on a dark night as a double concentration in the winter Milky Way, this showpiece can be found by following the "star chain" made up of Delta (δ), Alpha (α), Gamma (γ), and Eta (η) Persei northwestward toward Cassiopeia. It also forms a triangle with the

**Selected Objects — Perseus**

| Object | Type | Mag. | Size/Sep.<br>Per. | R.A. | (1950)<br>Dec. |
|---|---|---|---|---|---|
| *M-76 | ■ | 11 | 140″x70″ | $01^h39^m$ | +51°19′ |
| *NGC-869 | ○ | 4.4 | 35′ | $02^h17^m$ | +56°54′ |
| *NGC-884 | ○ | 4.7 | 35′ | $02^h19^m$ | +56°53′ |
| *M-34 | ○ | 5.5 | 30′ | $02^h39^m$ | +42°34′ |
| *Eta (η) | ★⁴ | 3.9,8.5,10,10.5 | 28″,66″,5″ | $02^h47^m$ | +55°41′ |
| *Beta (β) | Ӿ★ | 2.1-3.4 | $2.9^d$ | $03^h05^m$ | +40°46′ |
| Zeta (ζ) | ★³ | 3.0,9.5,9.5 | 13″,94″ | $03^h51^m$ | +31°44′ |
| Epsilon (ϵ) | ★² | 3.0,8.1 | 9″ | $03^h55^m$ | +39°52′ |
| *NGC-1499 | □ | -- | 145′x40′ | $04^h00^m$ | +36°17′ |
| NGC-1528 | ○ | 6.2 | 25′ | $04^h11^m$ | +51°07′ |

*Detailed in Close-Up

★ *Star*
★¹ *Bright Star*
★² *Double Star*
★³ *Triple Star*
ᗰ★ *Regular Variable*
ᑎ★ *Irregular Variable*
Ӿ★ *Eclipsing Variable*
○ *Open Cluster*
● *Globular Cluster*
■ *Planetary Nebula*
□ *Bright Diffuse Nebula*
§0 *Elliptical Galaxy*
§S *Spiral Galaxy*
§ʃ *Barred Spiral Galaxy*
§# *Peculiar/Irregular Galaxy*

stars Delta and Epsilon (ϵ) in the latter constellation.

NGC-869 has an integrated visual magnitude of about 4.4, and NGC-884 of 4.7. Both clusters have apparent diameters on the order of 35 minutes, although estimates run as high as 50 minutes each according to some authorities. In any case, their centers lie about 45 minutes of arc apart on the sky so these swarms do overlap. Star counts give about 350 and 300 members, respectively, agreeing with the visual impression that NGC-869 is richer than NGC-884.

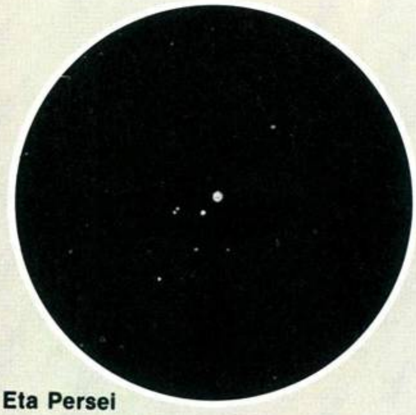
Although visible to the unaided eye and an easy object in binoculars, Messier strangely failed to include the Double Cluster in his famous list. Some say that it was too well-known and obvious to ever be mistaken for a comet, and therefore was not logged by the Frenchman. If this is the case, what about the Beehive (M-44) and Pleiades (M-45) Clusters which were included?

Having been bypassed by Messier, it fell to the thorough surveys of William Herschel to catalog the Double Cluster during his great sweeps of the heavens from England. The clusters are thus numbered 33 and 34 in his Class IV — very compressed and rich clusters of stars. The work of this great observer and his son John formed the basis of the *NGC* or *New General Catalogue*, from whose numbering system we get the designations used today for these and other deep-sky objects.

Even a 2-inch glass at just 25 power gives a thrilling view of this object, easily including both clusters in the same field of view. A 6 or 8-inch reflector at about 50 diameters places them at opposite sides of the eyepiece field in a spectacle that is difficult to describe adequately in words. As a rule, refractors and catadioptrics in this aperture range, as well as larger sized reflectors, will be able to fit only one cluster at a time in the view — greatly reducing the overall impact of seeing both objects simultaneously.

The *NGC* described the Double Cluster as "remarkable." Pickering included this duo in his roster of the 60 finest objects in the sky (which covered both northern and southern hemispheres). However, he made the interesting comment that "neither taken separately is the equal of M-41 (in Canis Major) or M-35 (in Gemini)." Northern observers may take exception with this great visual observer in this statement, but it must be realized that he worked from Jamaica where NGC-869 and NGC-884 are much lower in the sky than for us.

**M-76**



**Eta Persei**

**M-34**

**Above: The planetary nebula M-76 is one of the more challenging objects in Messier's famous list. Photograph by Bill Iburg. Above right: The fascinating multiple star Eta Persei as seen with a six-inch reflector at 150x. Drawing by James Mullaney. Right: The loose open cluster M-34 is a beautiful sight in small telescopes. Photograph by Jack Newton.**

Like many other star lovers, Smyth ranked the Double Cluster as "affording together one of the most brilliant telescopic objects in the heavens." He also mentioned a ruby and a garnet star in NGC-884 as seen in his 6-inch refractor. Webb too saw red stars here: "Two gorgeous clusters... With 64 (power) these superb masses are visible together, as well as a bright part north. 5.5-inch (refractor) showed a red star between them...9.3-inch (reflector) shows five red stars in all."

Other visual observers mention 8 or 9 ruddy stars here, mostly associated with NGC-884. These M-type supergiants sprinkled amid the glittering host of hot blue-white A and B-type suns provide a display of heavenly color that will thrill and excite any star lover. Even a 3 or 4-inch glass will show these contrasting tints on a dark night.

Olcott considered the Double Cluster "a wonderful object...one of the finest clusters for a small telescope. The field is simply sown with scintillating stars and the contrasting colors are very beautiful." Barns added: "Two splendid naked-eye clusters...overlapping so as to appear physically connected...stars blue-white and intense...vivid ruby variable in 884." The former observer worked with a 3-inch refractor, while the latter used a homemade 10-inch reflector.

Still other impressions are to be found. Burnham called this duo "a wonderfully beautiful object for moderate telescopes. Among the all-time favorites for amateur observers... the pair forming one of the most impressive and spectacular objects in the entire heavens." And Muirden noted that "a low power reveals two brilliant open clusters, each larger than the Moon, set side by side against a background granular with faint stars. This is a superb object, one to which the observer returns again and again; one never tires of surveying this dazzling array of suns, and the only pity is that few telescopes can include both clusters fully in the same field of view."

Have these excited commentaries left out anything of importance concerning the visual aspect of the great Double Cluster? Decidedly yes! With your telescope, look at the arrangement of the fainter stars in each group as they increase in number toward the center of the cluster, with the brighter units encircling them. This produces a very obvious and striking depth effect — like looking into a tunnel of stars.

The area around these stellar swarms is also one of beauty and interest to telescopists. Note especially the wide cluster of stars designated NGC-957, just a degree east and slightly north of the Double Cluster itself (7.2 magnitude, 10 minutes diameter, 40 stars). Barns described this area as a "field shot with diamond-dust!"

We view the magnificent Double Cluster in Perseus from across a gulf of more than 7000 light-years — or some 40 quadrillion miles of interstellar space. As we gaze spellbound into the crowded glittering cores of these vast stellar communes, the thought that there must be someone "out there" among so many stars comes forcibly to mind for many observers. So strong is this feeling that we may well find the haunting words of Enrico Fermi on our lips: "Where are they?"

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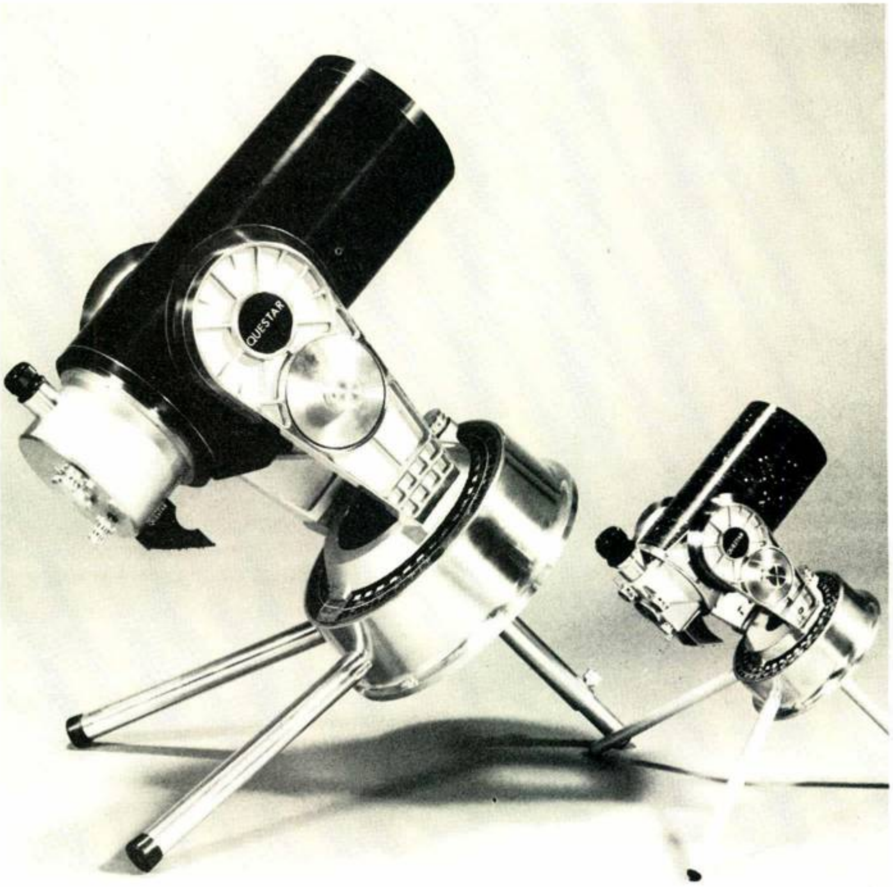

Because Questar's inventor loved fine instruments, he designed Questar for himself. He had begun dreaming about the kind of telescope he someday wanted to own, long before such a thing was considered a possibility.

To begin with, of course, there was to be a set of optics so fine that no amount of money, time, or human effort could improve upon it. Second, since he believed that the use of a telescope should not be a difficult physical chore, the size was extremely important: it should be easily portable. Preferably it would be small enough to be used on a table, where a person could sit in a relaxed position to observe and be able to have a writing surface at hand. And since he planned to carry it in his travels, it would be packaged handsomely in a piece of leather luggage.

Third, the accessories which were necessary for the enjoyment of a telescope were to be built in and should have fingertip controls within easy reach.

Fourth, the mechanical design must incorporate a means of putting the telescope into its polar equatorial position at a moment's notice and without the need of a separate tripod.

Fifth, the versatility that he visualized would make this instrument equally suitable for nature studies in the field. It also should be able to focus on close objects, which no other telescope in the world could do.

Sixth, the design must be photovisual so that he could record on film whatever these superior optics would present to the eye.

And finally, the instrument must be of rugged construction and vibrationless, without the aggravating oscillations of long-tubed conventional telescopes.

* * *

As we have said, this was the dream, but one lacking the possibility of fulfillment within the state of the art at that time. However, in the 1940's an important discovery in optics occurred. When Maksutov published, in the *Journal of the Optical Society of America*, a paper on his mixed lens-mirror, or catadioptric, system, it was immediately apparent to Questar's designer, Lawrence Braymer, that this break-through in optics would make possible a miniaturized version of the astronomical telescope which he had for so long wanted to build.

The Questar telescope reached the market in 1954: 3.5 inches of aperture with a 7-foot focal length in a sealed tube only 8 inches long, and with all the built-in conveniences that he had planned. These included a wide-field finder, power changes without changing eyepieces, smooth manual controls in altitude and azimuth, safety clutches, setting circles, a sidereal clock, and synchronous motor drive. Moreover, a totally safe solar filter had become an additional feature created for the solar observer.

Included, also, were legs for a table-top polar equatorial position; and as the design had progressed it had come to include two other conveniences: a map of the moon anodized on the barrel and a chart of the stars anodized on an aluminum sleeve to slip over the barrel. The chart revolves for monthly star settings and slides forward to serve as a dewcap. Both charts make other maps unnecessary during observing sessions.

Most remarkable of all were the optics—this was a system so fine that it has consistently delivered resolution surpassing its theoretical limits. Throughout its subsequent history, the care and precision with which every set of optics has been made and star tested has earned for the Questar telescope its reputation as the finest in the world.

* * *

Other Questars have followed over the years—the Seven, which is twice the size of its world-famous predecessor, has twice the resolving power and four times the light grasp; and more recently, the Questar 700. The latter is an f/8 telephoto lens for the photographer, and *Modern Photography* has simply called it "the best." The 700 guarantees perfection and flatness of field from edge to edge; also, precise focusing from infinity to 10 feet with a single turn of the focusing ring.

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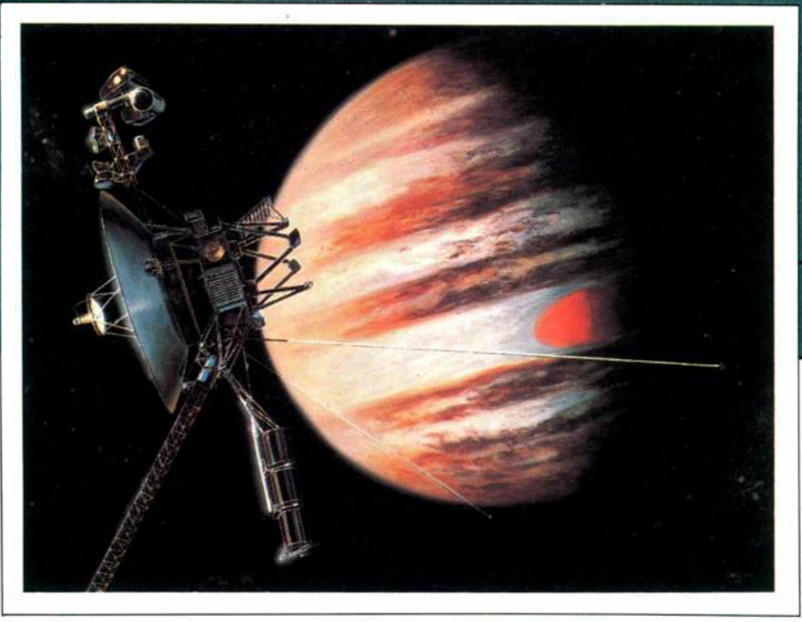

John Clark

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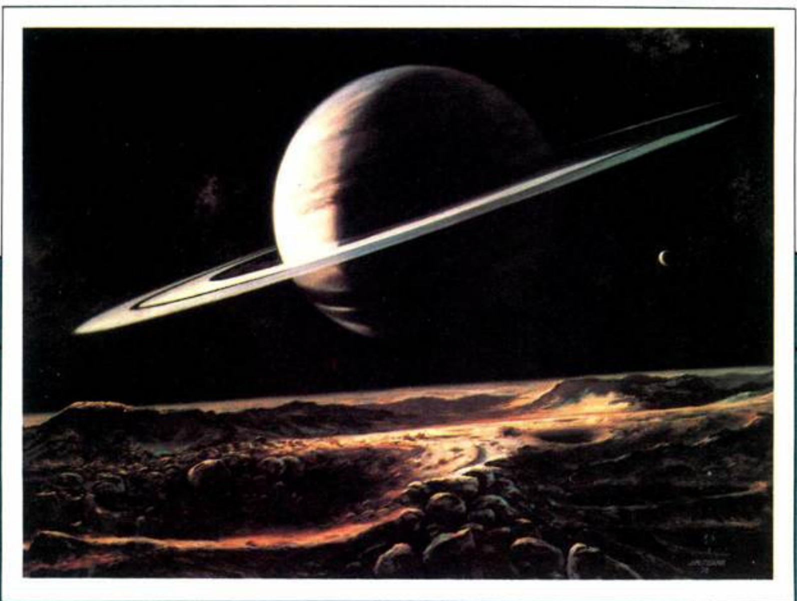

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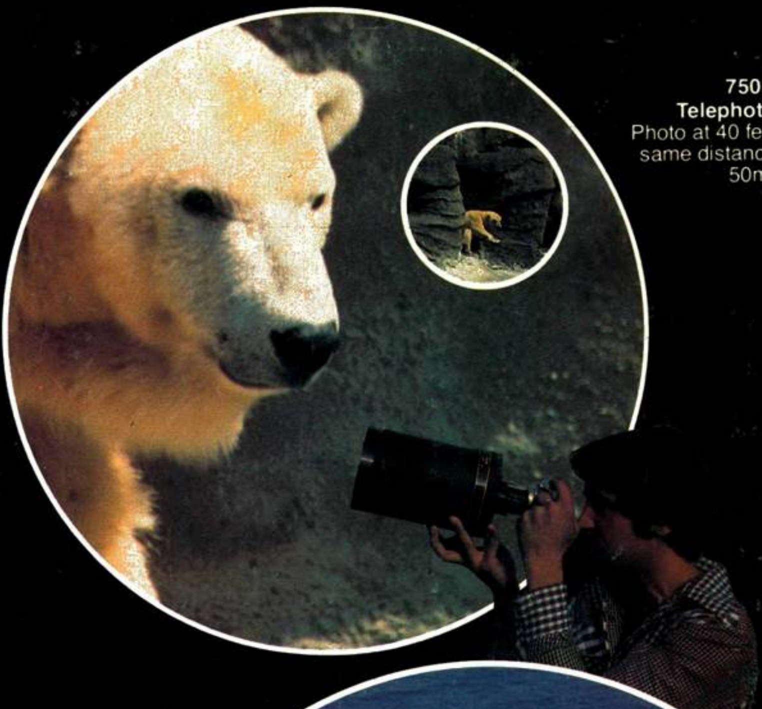
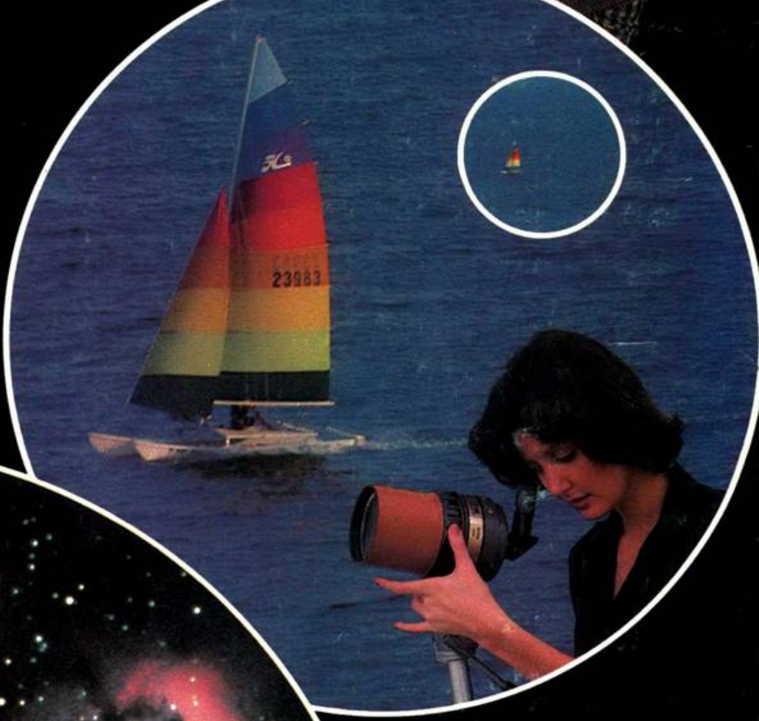
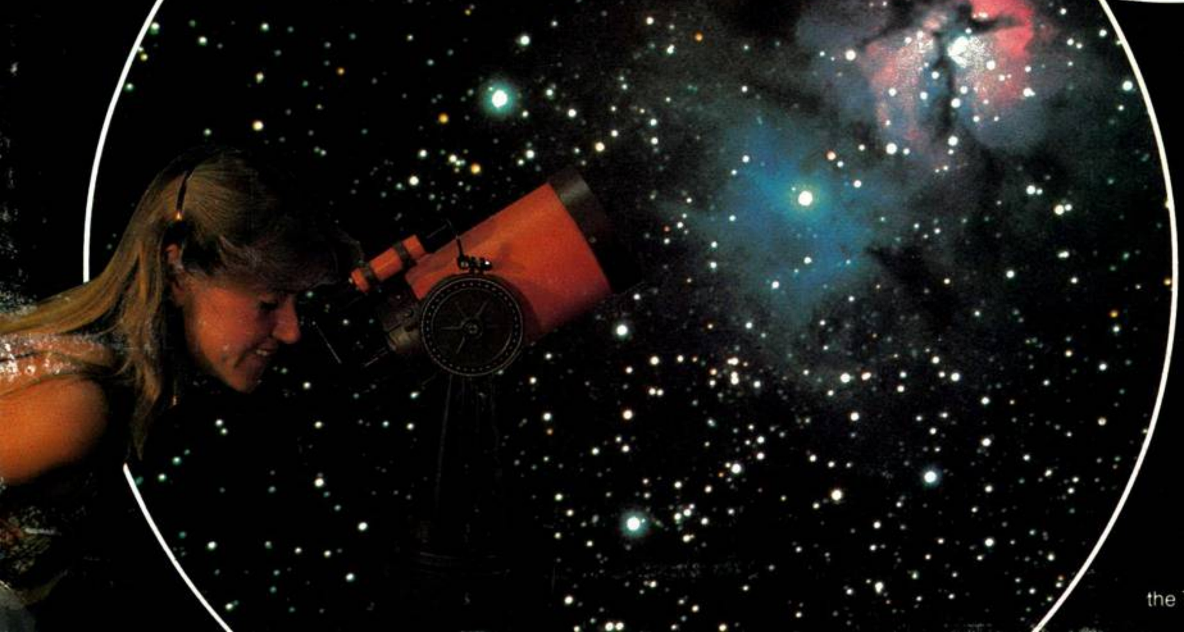


**750mm F/6 Telephoto Lens.** Photo at 40 feet. Inset same distance with a 50mm lens.



**C90 Spotting Scope.** Photo with a C5 lens at 3/8 mile. Inset same distance with a 50mm lens.



**C5 Telescope.** Photo with a C8 telescope of the Trifid Nebula M20.